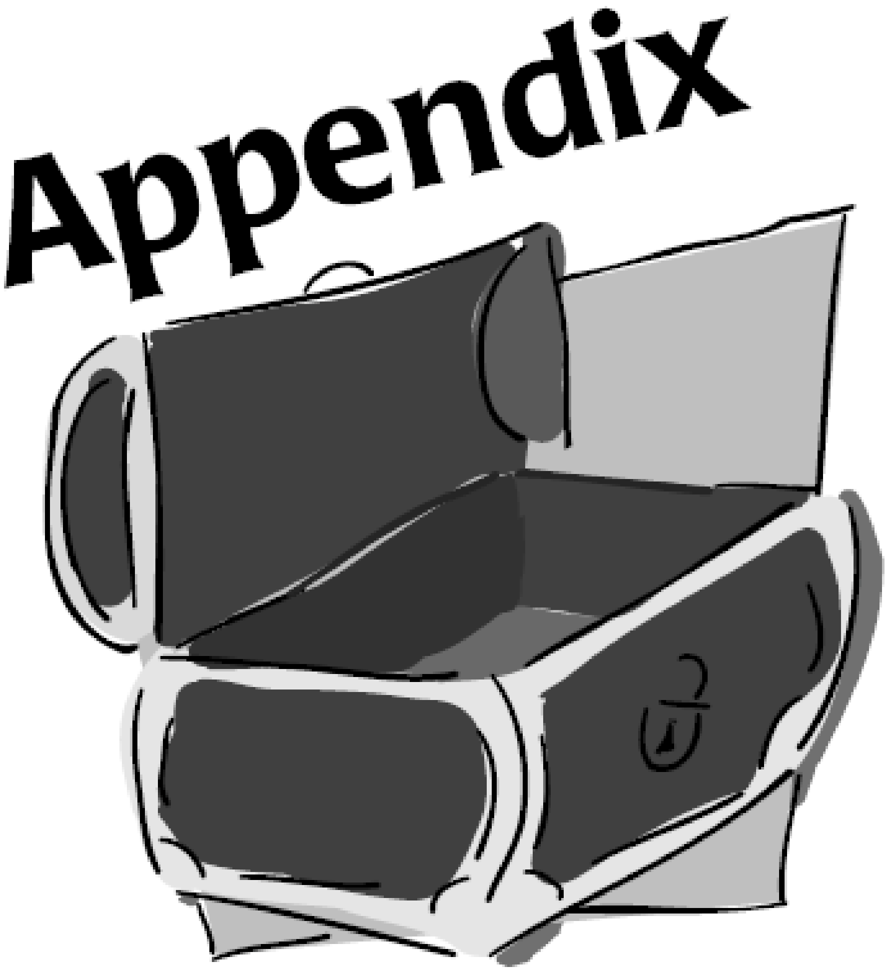

Appendix

Ice Seasonality Investigation
Site Definition Sheet

School Name:____

Observer Names: ____

Date: ___________________________ Check one: ❒ New Site ❒ Metadata Update

Study Site name (give your site a unique name): _______________________________________

Type of Site: Check one: ❒ **River/Creek** ❒ **Lake/Pond**

Coordinates: Latitude: ____________________ ❒ N or ❒ S (check one)
Longitude: ____________________ ❒ E or ❒ W (check one)
Elevation: _____ meters
Source of Location Data (check one): ❒ GPS ❒ Other
If other, describe: ____

Source of Meteorological Data:
Temperature data: ❒ GLOBE Atmospheric Site ❒ National Weather Service
❒ Airstrip data ❒ Newspaper/local media reports

Snow data: ❒ GLOBE Atmospheric Site ❒ National Weather Service
❒ Airstrip data ❒ Newspaper/local media reports ❒ Observation

If possible, provide some location information about the source of your meteorological data:
Distance to Ice Site: _________kilometers;
Direction to Ice Site: ❒ N ❒ NE ❒ E ❒ SE ❒ S ❒ SW ❒ W ❒ NW

OR

Latitude: ____________________ ❒ N or ❒ S (check one)
Longitude: ____________________ ❒ E or ❒ W (check one)

If a GLOBE Atmosphere Site is being used as the source of meteorological data for your Ice Seasonality Site, please complete the following:
Atmosphere Site: ATM-________
Distance to Ice Site: _________meters;
Direction to Ice Site: ❒ N ❒ NE ❒ E ❒ SE ❒ S ❒ SW ❒ W ❒ NW

Driving and/or walking directions: Provide directions to the site from some well-known landmark (school, cross roads, etc.). If appropriate, include walking directions from where your vehicle is parked to the Ice Site access/photo vantage point(s).

____
____
____
____

Site Biome:
The site is in the following natural biome (check one – definitions are found on the GLOBE Seasons and Biomes website):

❒ Tundra ❒ Taiga/Boreal Forest ❒ Montane
❒ Temperate Conifer Forest
❒ Temperate Deciduous/Mixed Forest
❒ Tropical/Subtropical Moist Deciduous Forest
❒ Tropical/Subtropical Dry Deciduous Forest
❒ Tropical/Subtropical Coniferous Forest
❒ Mediterranean ❒ Tropical Grasslands ❒ Temperate Grasslands
❒ Desert/Xeric ❒ Flooded Grasslands ❒ Mangroves

The natural condition of the site has been modified by human activity in the following way (check one):

❒ Urban (dense settlement) ❒ Rural (villages)
❒ Croplands/Agriculture ❒ Rangeland/Grazing ❒ Forestry
❒ Little Human Influence ❒ No Human Influence

Sketch/Map/Image of site (geography, main features, etc):

Standard Photograph Set of River Ice/Lake Ice Observation Site:

For a **River Ice site**, the Standard Photograph Set includes three photos: Across, Upstream, and Downstream.

For a **Lake/Pond Ice site**, the Standard Photograph Set needs to be defined by you and can include up to 6 photos. If this is a **Lake/Pond site**, provide names for the *photo views* in your standard photo set:

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________

Your Site Definition includes taking one Standard Photograph Set. When you download the photos from your camera, rename them to follow the convention *study site ID_ date_ photo view* (so the format would be: *ICE-99_YYMMDD_XXXXXX* where *XXXXXX* is *Up, Down, or Across for River Ice sites; or the names you chose above for Lake/Pond Ice sites*).

Enter the filename and annotation comments for each photo here:

Photo 1: ICE-___ _________ _______________

Comments:____

Photo 2: ICE-___ _________ _______________

Comments:____

Photo 3: ICE-___ _________ _______________

Comments:____

Photo 4: ICE-___ _________ _______________

Comments:____

Photo 5: ICE-___ _________ _______________

Comments:____

Photo 6: ICE-___ _________ _______________

Comments:____

Ice Seasonality Investigation
River Freeze-Up Data Sheet

School Name: ___________________________________ Study Site: ICE-____________
Observer Names:____
Date: Year:____________ Month: ____________ Day: ___________
Local Time (hour:min): _______________ Universal Time (hour:min): ______________

General Freeze-Up Ice Observations:

Upstream (border ice only):	
Estimate fraction of width covered by border ice:	_______ %
Changes in border ice:	❒ None ❒ Fractured ❒ Flooding ❒ Movement
Downstream (border ice only):	
Estimate fraction of width covered by border ice:	_______ %
Changes in border ice:	❒ None ❒ Fractured ❒ Flooding ❒ Movement
Across stream (ice in open water only):	
Ice types:	❒ None ❒ Frazil ❒ Pancakes (< 3 m across) ❒ Floes (> 3 m across)
Frost smoke?	❒ Yes ❒ No

Ice surface: **(may choose more than 1)**	❒ Smooth ❒ Rough ❒ Blocky/Broken/Jumbled ❒ Wet/Flooded ❒ Holes/Leads ❒ Bare (melting) ❒ Ice jam
Snow on ice:	❒ None (cold) ❒ New, patchy ❒ New, continuous ❒ Stable with new snow layer ❒ Stable/No change ❒ Wind redistributed ❒ Icy crust ❒ Melting/Wet ❒ None (warm)
Snow on bank/shore:	❒ None ❒ New, patchy ❒ New, continuous ❒ Stable with new snow layer ❒ Stable/No change ❒ Wind redistributed ❒ Icy crust ❒ Melting/Wet

Environmental Observations:

Cloud Cover:	• *If Three-quarters or More of the Sky is Visible:* (Check one) *No Clouds* ❑ 0%-No Clouds *Clear* ❑ <10% Clouds *Isolated* ❑ 10-25% Clouds *Scattered* ❑ 25-50% Clouds *Broken* ❑ 50-90% Clouds *Overcast* ❑ >90% Clouds • *If View of More than One-quarter of the Sky is Blocked:* ***Obscured*** ❑ Check here *Why is the view of the sky blocked?* (Check all that apply) ❑ Blowing Snow ❑ Heavy Snow ❑ Heavy Rain ❑ Fog ❑ Spray ❑ Volcanic Ash ❑ Smoke ❑ Dust ❑ Sand ❑ Haze
Wind*:	❒ Calm (<0.3 m/s) ❒ Light wind (0.3-5.5 m/s) ❒ Windy (>5.5 m/s)
Precipitation type:	❒ None ❒ Snow flurries ❒ Snowing ❒ Fog/Drizzle ❒ Rain ❒ Freezing rain

*See *Ice Seasonality Investigation Field Guide* for definitions.

Environmental Observation Comments:

____

____

Standard Photograph Set of River Ice Freeze-Up:
When you download the photos from your camera, rename them to follow the convention *study site ID_ date_ photo view* (so the format would be: *ICE-99_YYMMDD_XXXXXX* where *XXXXXX* is *Up, Down, or Across*).

Enter the filename, and optional comments, for each photo here:

Across photo: ICE-___ _ ___________ _Across

Comments:____

Upstream photo: ICE-___ _ ___________ _Up

Comments:____

Downstream photo: ICE-___ _ ___________ _Down

Comments:____

Optional Additional Photographs of River Ice Freeze-Up:
Enter the filename of each photo and accompanying comments here:

Additional photo 1: ICE-___ _ ___________ _ __________________

Comments:____

Additional photo 2: ICE-___ _ ___________ _ __________________

Comments:____

Additional photo 3: ICE-___ _ ___________ _ __________________

Comments:____

Other Comments:

____

____

____

Ice Seasonality Investigation
River Break-Up Data Sheet

School Name: ____________________________________ Study Site: ICE-____________
Observer Names:____
Date: Year:____________ Month: ____________ Day: ___________
Local Time (hour:min): _______________ Universal Time (hour:min): ______________

General Break-Up Ice Observations:

Ice present?	❒ Yes ❒ No
Static Ice:	
Upstream:	
Ice fractured:	❒ Yes ❒ No
Water on ice:	❒ Yes ❒ No
Holes in ice:	❒ Yes ❒ No
Channel through ice:	❒ Yes ❒ No
Downstream:	
Ice fractured:	❒ Yes ❒ No
Water on ice:	❒ Yes ❒ No
Holes in ice:	❒ Yes ❒ No
Channel through ice:	❒ Yes ❒ No
Moving ice:	
Upstream:	❒ Yes ❒ No
Downstream:	❒ Yes ❒ No
Ice surface: **(may choose more than one)**	❒ Smooth ❒ Rough ❒ Blocky/Broken/Jumbled ❒ Melt ponds ❒ Wet/Flooded ❒ Ice jam

Environmental Observations:

Cloud Cover:	• *If Three-quarters or More of the Sky is Visible:* (Check one) *No Clouds* ❑ 0%-No Clouds *Clear* ❑ <10% Clouds *Isolated* ❑ 10-25% Clouds *Scattered* ❑ 25-50% Clouds *Broken* ❑ 50-90% Clouds *Overcast* ❑ >90% Clouds • *If View of More than One-quarter of the Sky is Blocked:* ***Obscured*** ❑ Check here *Why is the view of the sky blocked?* (Check all that apply) ❑ Blowing Snow ❑ Heavy Snow ❑ Heavy Rain ❑ Fog ❑ Spray ❑ Volcanic Ash ❑ Smoke ❑ Dust ❑ Sand ❑ Haze
Wind*:	❒ Calm (<0.3 m/s) ❒ Light wind (0.3-5.5 m/s) ❒ Windy (>5.5 m/s)
Precipitation type:	❒ None ❒ Snow flurries ❒ Snowing ❒ Fog/Drizzle ❒ Rain ❒ Freezing rain

*See *Ice Seasonality Investigation Field Guide* for definitions.

Environmental Observation Comments:

____
____
____
____

Standard Photograph Set of River Ice Break-Up:
When you download the photos from your camera, rename them to follow the convention *study site ID_ date_ photo view* (so the format would be: *ICE-99_YYMMDD_XXXXXX* where *XXXXXX* is *Up, Down, or Across*).

Enter the filename, and optional comments, for each photo here:

Across photo: ICE-___ _ ___________ _Across

Comments:____

Upstream photo: ICE-___ _ ___________ _Up

Comments:____

Downstream photo: ICE-___ _ ___________ _Down

Comments:____

Optional Additional Photographs of River Ice Break-Up:
Enter the filename of each photo and accompanying comments here:

Additional photo 1: ICE-___ _ ___________ _ ________________

Comments:____

Additional photo 2: ICE-___ _ ___________ _ ________________

Comments:____

Additional photo 3: ICE-___ _ ___________ _ ________________

Comments:____

Other Comments:

____
____
____

Ice Seasonality Investigation
Lake/Pond Freeze-Up Data Sheet

School Name: ____________________________________ Study Site: ICE-_____________
Observer Names:____
Date: Year:____________ Month: ____________ Day: ___________
Local Time (hour:min): _______________ Universal Time (hour:min): ______________

General Freeze-Up Ice Observations:

Ice Cover: Estimate fraction of area covered by ice:	_______ %
Ice Cover Change: Changes in ice:	❒ None ❒ Fractured ❒ Flooding ❒ Movement
Frost smoke?	❒ Yes ❒ No

Ice surface: (may choose more than one)	❒ Smooth ❒ Rough ❒ Blocky/Broken/Jumbled ❒ Wet/Flooded ❒ Holes/Leads ❒ Bare (melting) ❒ Ice jam
Snow on ice:	❒ None (cold) ❒ New, patchy ❒ New, continuous ❒ Stable with new snow layer ❒ Stable/No change ❒ Wind redistributed ❒ Icy crust ❒ Melting/Wet ❒ None (warm)
Snow on bank/shore:	❒ None ❒ New, patchy ❒ New, continuous ❒ Stable with new snow layer ❒ Stable/No change ❒ Wind redistributed ❒ Icy crust ❒ Melting/Wet

Environmental Observations:

Cloud Cover:	• *If Three-quarters or More of the Sky is Visible:* (Check one) *No Clouds* ❑ 0%-No Clouds; *Clear* ❑ <10% Clouds; *Isolated* ❑ 10-25% Clouds; *Scattered* ❑ 25-50% Clouds *Broken* ❑ 50-90% Clouds; *Overcast* ❑ >90% Clouds • *If View of More than One-quarter of the Sky is Blocked:* ***Obscured*** ❑ Check here *Why is the view of the sky blocked?* (Check all that apply) ❑ Blowing Snow ❑ Heavy Snow ❑ Heavy Rain ❑ Fog ❑ Spray ❑ Volcanic Ash ❑ Smoke ❑ Dust ❑ Sand ❑ Haze
Wind*:	❒ Calm (<0.3 m/s) ❒ Light wind (0.3-5.5 m/s) ❒ Windy (>5.5 m/s)
Precipitation type:	❒ None ❒ Snow flurries ❒ Snowing ❒ Fog/Drizzle ❒ Rain ❒ Freezing rain

*See *Ice Seasonality Investigation Field Guide* for definitions.

Environmental Observation Comments:

____

____

Standard Photograph Set of Lake Ice Freeze-Up:

When you download the photos from your camera, rename them to follow the convention *study site ID_ date_ photo view* (so the format would be: *ICE-99_YYMMDD_XXXXXX* where *XXXXXX* is *the name you chose for the photo view when you defined the site*).

Enter the filename, and optional comments, for each photo here:

Photo 1:	ICE-___________________________________
Comments:	____
Photo 2:	ICE-___________________________________
Comments:	____
Photo 3:	ICE-___________________________________
Comments:	____
Photo 4:	ICE-___________________________________
Comments:	____
Photo 5:	ICE-___________________________________
Comments:	____
Photo 6:	ICE-___________________________________
Comments:	____

Optional Photographs of Lake Ice Freeze-Up:
Enter the filename of each photo and accompanying comments here:

Additional photo 1: ICE-___ _________ _______________

Comments:____

Additional photo 2: ICE-___ _________ _______________

Comments:____

Additional photo 3: ICE-___ _________ _______________

Comments:____

Other Comments:
____
____
____
____

Ice Seasonality Investigation

Lake/Pond Break-Up Data Sheet

School Name: ____________________________________ Study Site: ICE-_____________
Observer Names:____
Date: Year:____________ Month: ____________ Day: ___________
Local Time (hour:min): _______________ Universal Time (hour:min): ______________

General Break-Up Ice Observations:

Ice present?	❐ Yes ❐ No
Ice Cover: Estimate fraction of area covered by ice:	_______ %
Ice Cover Appearance: Ice fractured: Water on ice: Holes in ice: Ice broken into pieces Ice blocks movement	 ❐ Yes ❐ No ❐ Yes ❐ No ❐ Yes ❐ No ❐ Yes ❐ No ❐ Yes ❐ No
Ice surface: **(may choose more than one)**	❐ Smooth ❐ Rough ❐ Blocky/Broken/Jumbled ❐ Ice jam ❐ Holes/Leads ❐ Melt ponds ❐ Wet/Flooded ❐ Moat

Environmental Observations:

Cloud Cover:	• *If Three-quarters or More of the Sky is Visible:* (Check one) *No Clouds* ❑ 0%-No Clouds; *Clear* ❑ <10% Clouds; *Isolated* ❑ 10-25% Clouds; *Scattered* ❑ 25-50% Clouds *Broken* ❑ 50-90% Clouds; *Overcast* ❑ >90% Clouds • *If View of More than One-quarter of the Sky is Blocked:* ***Obscured*** ❑ Check here *Why is the view of the sky blocked?* (Check all that apply) ❑ Blowing Snow ❑ Heavy Snow ❑ Heavy Rain ❑ Fog ❑ Spray ❑ Volcanic Ash ❑ Smoke ❑ Dust ❑ Sand ❑ Haze
Wind*:	❐ Calm (<0.3 m/s) ❐ Light wind (0.3-5.5 m/s) ❐ Windy (>5.5 m/s)
Precipitation type:	❐ None ❐ Snow flurries ❐ Snowing ❐ Fog/Drizzle ❐ Rain ❐ Freezing rain

*See *Ice Seasonality Investigation Field Guide* for definitions.

Environmental Observation Comments:

____
____
____
____

Standard Photograph Set of Lake Ice Break-Up:
When you download the photos from your camera, rename them to follow the convention *study site ID_ date_ photo view* (so the format would be: *ICE-99_YYMMDD_XXXXXX* where *XXXXXX* is *the name you chose for the photo view when you defined the site*).

Enter the filename, and optional comments, for each photo here:

Photo 1: ICE-__ _ __________ _ ________________

Comments:____

Photo 2: ICE-__ _ __________ _ ________________

Comments:____

Photo 3: ICE-__ _ __________ _ ________________

Comments:____

Photo 4: ICE-__ _ __________ _ ________________

Comments:____

Photo 5: ICE-__ _ __________ _ ________________

Comments:____

Photo 6: ICE-__ _ __________ _ ________________

Comments:____

Optional Additional Photographs of Lake Ice Break-Up:
Enter the filename of each photo and accompanying comments here:

Additional photo 1: ICE-________________________________

Comments:____

Additional photo 2: ICE-________________________________

Comments:____

Additional photo 3: ICE-________________________________

Comments:____

Other Comments:

Ice Seasonality Investigation

Annual Summary Data Sheet

School Name: ___________________________________ Study Site: ICE-____________

Observer Names:____

Period of Observation (YYMMDD): ______________ to ______________

Ice Seasonality Milestones:

FREEZE-UP	**Date observed** (format: *YYMMDD*)
Date of first* minimum air temperature < 0°C:	________________________
Date of continuous** minimum air temperature < 0°C	________________________
Date of first mean daily air temperature < 0°C:	________________________
Date of continuous mean daily air temperature < 0°C:	________________________
Date of first maximum air temperature < 0°C:	________________________
Date of continuous first maximum air temperature < 0°C:	________________________
Date of first snow:	________________________
Date of continuous snow on the ground:	________________________
Date of first appearance of ice on the site:	________________________
Date of 100% ice cover on the site:	________________________
BREAK-UP	
Date of first maximum air temperature > 0°C:	________________________
Date of continuous maximum air temperature > 0°C:	________________________
Date of first mean daily air temperature > 0°C:	________________________
Date of continuous mean daily air temperature > 0°C:	________________________
Date of first minimum air temperature > 0°C:	________________________
Date of continuous minimum air temperature > 0°C:	________________________
Date of complete disappearance of snow on the ice:	________________________
Date of 0% ice cover on the site:	________________________

* *first day when this phenomenon occurs*
** *first day this phenomenon becomes continuous (may be same as *)*

See the **Annual Summary Guide** for a complete description of how to determine milestone dates.

Ice Seasonality Investigation

Ice Seasonality and Science Education Standards

Different aspects of the Ice Seasonality protocol can be aligned with all or part of most of the basic content standards for all grades. The exception is "Life Science", although this category could be addressed if the Ice Seasonality Protocol is incorporated into an "Environmental Sciences" elective.

The table below summarizes some examples of how the Ice Seasonality Protocol can be used to address National Science Education Standards. Italics indicate a subset of the Content Standards and boldfaced indicates a possible activity or concept from the Ice Seasonality Protocol that addresses it.

Content Standards	Grades K-4	Grades 5-8	Grades 9-12
Unifying Concepts and Processes	*Change, constancy and measurement:* **observing and quantifying variation and change in nature**	*Change, constancy and measurement:* **exploring the temporal and spatial variation of ice seasonality (their site and other GLOBE sites)**	*Evidence, models and explanation:* **correlating ice seasonality with other environmental data sets (air temp., green-up/green down*) to test an hypothesis**
Science as Inquiry	*Abilities necessary to do scientific inquiry* **formulate simple question, collect data**	*Abilities necessary to do scientific inquiry* **formulate question, data collection and simple analysis of data (graphing)**	*Abilities necessary to do scientific inquiry:* **formulate hypothesis, data collection and statistical analysis of data, deriving other values from the collected data**
Physical Science	*Properties of objects and materials:* **heating vs cooling, liquid vs solid, movement**	*Transfer of energy:* **freezing and melting, heat flux**	*Structure and properties of matter:* **ice crystallography, density, thermal conductivity**
Earth and Space Science	*Properties of earth materials:* **heating vs cooling, liquid vs solid, movement**	*N/A*	*Energy in the earth system:* **freezing, melting, heat flux, energy balance**

Content Standards	Grades K-4	Grades 5-8	Grades 9-12
Science and Technology	*Abilities to distinguish between natural objects and objects made by humans:* **learning to use simple tools to make scientific observations**	*Understanding about science and technology;* **use of simple tools and procedures to collect scientific data**	*Understanding about science and technology* **use of tools and procedures to collect and analyze scientific data**
History and Nature of Science	*Science as a human endeavor:* **learn to observe and document natural phenomena**	*Science as a human endeavor:* **learn to collect and analyze data**	*Nature of scientific knowledge:* **use appropriate mathematics, statistics and data analysis techniques to understand the data**

Teacher Resources

Historical Trends in Lake and River Ice Cover in the Northern Hemisphere (Science, 8 September 2000, Vol. 289, no. 5485, pp. 1743-1746).
Magnuson et al. (2000), describes the changes in the freeze-up and break-up dates of northern hemisphere lakes and rivers over several decades (http://www.sciencemag.org/cgi/content/full/289/5485/1743).

Climate Change 2001: Working Group II: Impacts, Adaptation and Vulnerability (Intergovernmental Panel on Climate Change)
Chapter 5. Ecosystems and Their Goods and Services –
5.7.3.1 Physical Conditions/5.7.3.1.1 Ice cover
Provides a short description of some of the environmental impacts of change in lake and river ice seasonality http://www.grida.no/climate/ipcc_tar/wg2/260.htm).

GLOBE web site – Teacher's Guide (http://www.globe.gov/tctg/tgtoc.jsp)
The GLOBE Teacher's Guide, CD Version 2.0, 2005.

Ice Seasonality Investigation

Complementary GLOBE Protocols and Learning Activities

The freshwater ice growth and decay model CLiMO (Duguay et al., 2003) uses the meteorological variables air temperature, precipitation, cloud cover, wind speed and relative humidity as forcing variables. It has been shown that air temperature and precipitation are the primary factors determining the ice growth and decay history. Cloud cover takes on a prominent role during the spring break-up.

Teachers should consider performing the following GLOBE protocols at the school's ice study sites so that students can see the relationships between the ice conditions and the forcing environmental conditions. This will require setting up an atmosphere study site within 100m of the ice study site. (The protocols are available at the following *Chapters, pages* the GLOBE Teacher's Guide CD-ROM, 2005):

1) **Cloud protocols** – *Atmosphere*, *pages 41-56* (including an activity that introduces the concept of estimating cover which is useful for both the clouds and ice);
2) **Temperature protocols** – maximum, minimum and current air temperature protocol, *Atmosphere*, *pages 162-181*;
   OR digital multi-day max/min/current air and soil temperatures protocol – *Atmosphere*, *pages 183-196*;
   OR Automated soil and air temperature monitoring protocol – *Atmosphere*, *pages 197-211*;
3) **Solid Precipitation Protocol** – *Atmosphere*, *pages 138-139* (measuring snow depth only - Precipitation Protocols/Solid Precipitation Protocol).

In order to obtain an integrated understanding of the fall-winter and winter-spring seasonal transitions, the following protocols may be performed at the same time as the ice seasonality protocol:

1) Snow and soil surface temperature protocol (based on the Surface Temperature Protocol, *Atmosphere*, *pages 212-229*) and
2) Budburst, Green-Up and Green-Down protocols, *Earth as a System, pages 50-107* (lake/river side vegetation), and
3) Arctic bird migration monitoring protocol, *Earth as a System, pages 164-173* (focusing on water fowl).

In addition, there are related material and activities in the *Earth as a System* Chapter that provide a broad background and develop useful skills:

- Introduction (*pages 5-44*) – The Seasonal Cycle and Scales of Understanding (local, regional and global)
- Seasons (*pages 197-274*) – learning activities
- Local Connections (*pages 373-456*) – learning activities
- Regional Connections (*pages 457-497*) – learning activities
- Global Connections (*pages 498-528*) – learning activities

Duguay, C.R., G.M. Flato, M.O. Jeffries, P. MeÅLnard,W.R. Rouse and K. Morris. 2003. Ice cover variability on shallow lakes at high latitudes: model simulations and observations. Hydrol. Process., ***17****(17), 3465–3483.*

Ice Seasonality Investigation
River Ice Glossary

It is important to keep in mind that moderately sized rivers rarely freeze to the bottom. Even during the coldest part of the winter, there is some running water below the ice through the deepest parts of the river channel.

Some Key Concepts and Terms

Some Properties of Water

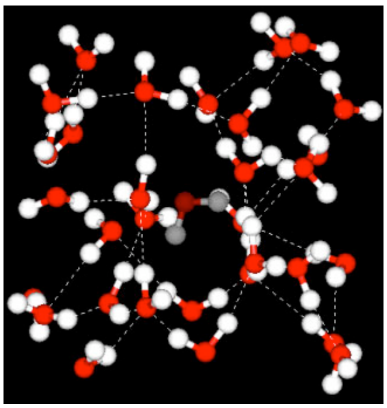
Water can exist in any one of three states: solid (ice), liquid (water) and gas (water vapor).

Fresh water has a maximum density at around 4°C: 1 g cm^3, 1 g ml, 1 kg liter, 1000 kg m^3, or 1 tonne m^3.

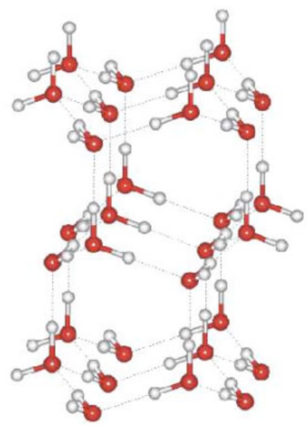
Water is the only substance where the maximum density does not occur when solidified (which is why ice floats on water)..

Solid water (ice) is the most ordered (least energetic) state of water while gas is the least ordered (highest energetic) state.

Water Phase Change



Liquid water can be thought of as a seething mass of H_2O molecules in which hydrogen-bonded clusters are continually forming, breaking apart, and re-forming. The more crowded and jumbled arrangement in liquid water can be sustained only by the greater amount thermal energy available above the freezing point (0°C). (Source: http://ssrl.slac.stanford.edu/nilssongroup/pages/project_liquid_structure.html)

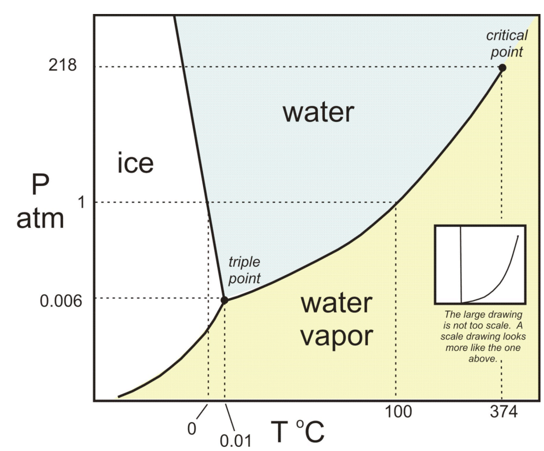


Notice the *greater openness* of the ice structure. This is necessary to ensure the strongest degree of hydrogen bonding in a uniform, extended crystal lattice. (Source: http://ssrl.slac.stanford.edu/nilssongroup/pages/project_liquid_structure.html)

A **phase change** is a change from one state to another without a change in chemical composition. These changes are induced by the effects of temperature and/or pressure:

The transitions are:
Solid-to-liquid transition - *melting*
Liquid-to-solid transition - *freezing*
Liquid-to-gas transition - *evaporation*
Gas-to-liquid transition - *condensation*
Solid-to-gas transition - *sublimation*
Gas-to-solid transition - *deposition*

(Source: http://serc.carleton.edu/NAGTWorkshops/petrology/teaching_activities_table_contents.html)



Energy, Temperature and Heat

Energy is defined as the capacity to do work (the amount of work one system is doing on another). There are two kinds of energy that are of interest here:

- Internal energy is defined as the energy associated with the random, disordered motion of molecules; it refers to the invisible microscopic energy on the atomic and molecular scale
- Kinetic energy is energy of motion. The kinetic energy of an object is the energy it possesses because of its motion.

Temperature measures the average kinetic energy of the particles in a substance. It measures the degree of heat (high energy) or cool (low energy) of a substance. Heat is defined as energy in transit.

Heat (internal energy) moves from a **high** temperature region to a **low** temperature region. This is called heat transfer.

Heat Transfer

Latent Heat

Latent heat is the energy required to change a substance from one state to another at constant temperature.

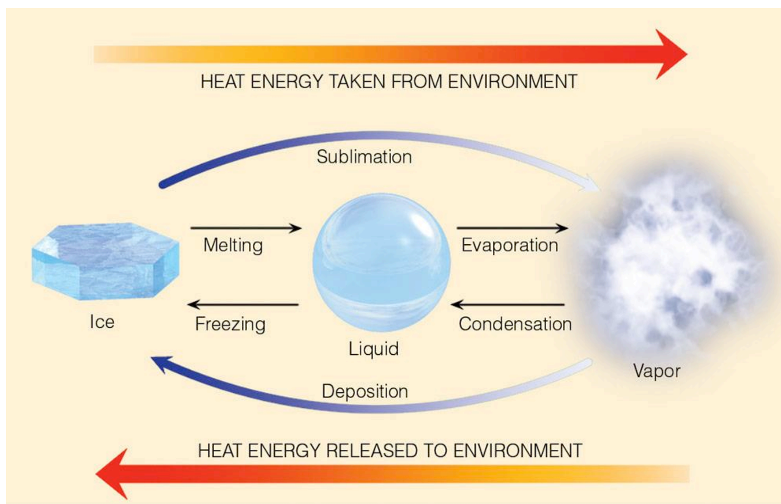
When a substance changes from one state to another, latent heat is added or released in the process.

LIQUID to VAPOR
Latent heat of evaporation is **taken** from the environment (about 540 cal per gram)

VAPOR to LIQUID
Latent heat of condensation is **released** to the environment

LIQUID to ICE
Latent heat of freezing is **released** to the environment (about 80 cal per gram)

ICE to LIQUID
Latent heat of fusion (melting) is **taken** from the environment

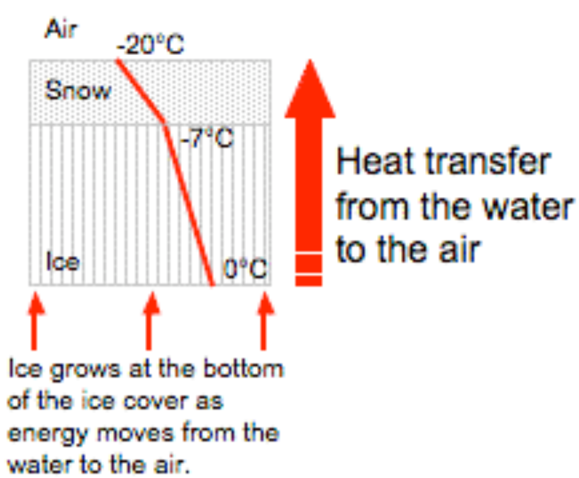


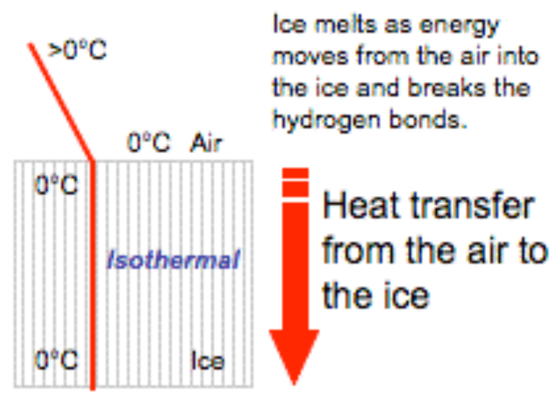
(Source: http://apollo.lsc.vsc.edu/classes/met130/notes/chapter2/lat_heat2.html)

Latent Heat of Freezing and Melting

The **latent heat of freezing** is the energy released from the water and added to the environment, in order for water to freeze into ice. When heat is subtracted from liquid water, the individual water molecules will slow down. They eventually slow to the point at which the hydrogen bonds do not allow the liquid to rotate anymore. Ice now develops. (Source: http://www.theweatherprediction.com/habyhints/19/)

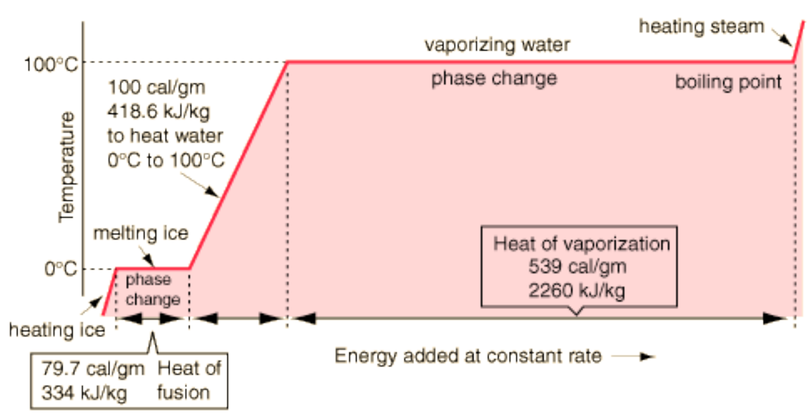
The **latent heat of fusion (melting)** is the energy that is taken from the environment and added to the ice to melt it into water. This energy is used to break the ice lattice bonds and allows the ice to go from a lower energetic state to a more energetic state (water). (Source: http://www.theweatherprediction.com/habyhints/19/)





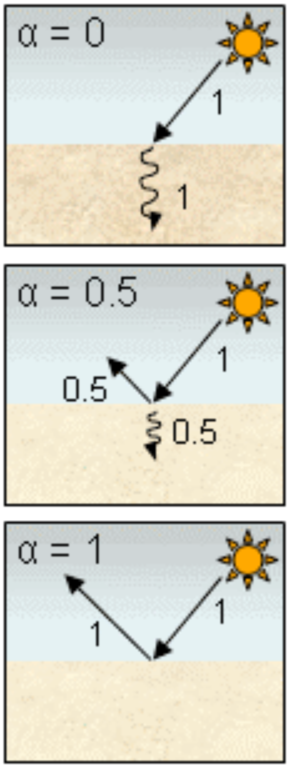
When water undergoes a phase change (a change from solid, liquid or gas to another phase) the temperature of the water stays the same. Energy is being used to either weaken the hydrogen bonds between water molecules or energy is being taken away from the water, which tightens the hydrogen bonds. When ice melts, energy is being taken from the environment and absorbed into the ice to loosen the hydrogen bonds. The temperature of the melting ice however stays the same until all the ice is melted. All hydrogen bonds must be broken from the solid state before energy can be used to increase the water's temperature.
(Source: http://www.theweatherprediction.com/habyhints/19/)

If heat were added at a constant rate to a mass of ice to take it through its phase changes to liquid water and then to steam, the energies required to accomplish the phase changes (the latent heat of fusion and latent heat of vaporization) would lead to plateaus in the temperature vs time graph.



(Source: http://hyperphysics.phy-astr.gsu.edu/Hbase/thermo/phase.html#c1)

Albedo



(Source: National Snow and Ice Data Center)

Albedo is a measure of reflectivity of a surface or body. It is the ratio of electromagnetic radiation (EM radiation) reflected to the amount incident upon it. The fraction, usually expressed as a percentage from 0% to 100% (or as a dimensionless value between 0 and 1), is an important concept in climatology and astronomy.

A **perfect absorber** does not reflect any of the sunlight that strikes it. It looks black and has an albedo of 0. When an object absorbs most of the light that hits it, it looks dark and has a low albedo.

A **perfect reflector** reflects all the sunlight that strikes it. It looks white and has an albedo of 1. Objects that reflect most of the light that hit them appear bright and have a high albedo.

Albedo Values for Common Earth Surfaces

Surface	Albedo
Absolute black surface	0.0
Forest	0.05-0.2
Water	0.06
Grassland and cropland	0.1-0.25
Dark colored soil surface	0.1-0.2
Dry sandy soil	0.25-0.45
Dry clay soil	0.15-0.35
Sand	0.2-0.4
Mean albedo of the Earth	0.36
Granite	0.3-0.35
Glacial Ice	0.3-0.4
Light colored soil surfaces	0.4-0.5
Dry salt cover	0.5
Tops of clouds	0.6-0.9
Fresh, deep snow	0.9
Absolute white surface	1.0

River Ice Freeze-up

Freeze-up is the seasonal formation of a continuous ice cover on a body of water. An ice cover is a layer of ice on top of some other feature, usually the surface of a lake or pond (but also rivers and seas/oceans).
(Source: http://amsglossary.allenpress.com/glossary/). In rivers, an ice cover does not form when the water velocity exceeds about 0.6 ms^{-1} (Ashton, 1986).

Meteorological factors such as air temperature, precipitation, and radiation balance coupled with physical characteristics of the rivers and ice (river geometry; water velocity; snow depth; ice thickness, type and albedo) lead to complex interactions and feedbacks that affect the timing of freeze-up and break-up (and hence ice cover duration) each year.

Ice Fog or Frost Smoke

Ice fog or **frost smoke** is a type of fog, composed of suspended particles of ice. It occurs at very low temperatures, and usually in clear, calm weather in high latitudes. Ice fog is rare at temperatures higher than −30°C, and increases in frequency with decreasing temperature until it is almost always present at air temperatures of −45°C in the vicinity of a source of water vapor such as the open water of fast-flowing streams. (Source: http://amsglossary.allenpress.com/glossary)

Frost smoke seen during the freeze up of the Chena River AK on 4 November 2006. (Photograph: Martin Jeffries)

Frost smoke seen forming over an area of open water on the Chena River during the winter. The orange arrow indicates the location of the frost smoke plume. (Photograph: Martin Jeffries)

New Ice

A **thermal ice cover** grows when ice crystals form on the surface and rapidly link together to create a thin ice sheet. Thermal ice forms when river water velocities less than 0.6 m/s and water temperatures below the freezing point (0°C). Once the thin ice sheet has formed, it begins to grow downward by freezing at the ice-water interface. Heat loss is retarded by the ice cover itself and by snow cover that may be present. (Source: New Brunswick River Ice Manual)

Sheet ice is ice formed in a "smooth" thin layer on a water surface by the coagulation of ice crystals through rapid freezing (Source: http://amsglossary.allenpress.com/glossary/). It is also defined as a smooth, continuous ice cover formed by in situ freezing or by the arrest and juxtaposition of ice floes in a single layer (Source: CRREL). On rivers, sheet ice may grow to "fill in" areas between already existing ice.

A thin, new ice sheet that grew over the entire river in only a few days. Little border ice (defined below) formed during freeze-up. (Innoko River, AK, 15 October 2008), (Photograph: Joy Hamilton)

An example of a well-established river ice sheet in mid-winter.
(Photograph: Dennis Kalma)

Border ice is an ice sheet in the form of a long border attached to the bank or shore. It is also called shore ice. (Source: http://www.expertglossary.com/weather/definition/border-ice). Border ice forms where the water flow is slow.

New border ice on the Chatanika River AK, Fall 2006.
(Photograph: Martin Jeffries)

Border ice grows laterally toward mid-stream. This border ice has snow on it. (Source: New Brunswick River Ice Manual)

Black (congelation) and White (snow) Ice

There are several kinds of ice that form on rivers. Two of these are black (congelation) ice and white (snow ice).

Black ice or congelation ice is ice that appears dark in color because it permits significant light transmission to the underlying water (Source: http://amsglossary.allenpress.com/glossary/).

White ice or snow ice is ice with a white appearance caused by the occurrence of bubbles within the ice. It is formed from refrozen slush. The bubbles increase the scattering of all wavelengths of light in contrast to the appearance of bubble-free black ice (Source: http://amsglossary.allenpress.com/glossary/).

A **temperature gradient** is the temperature difference between two points divided by the distance between those points.

Black and White Ice Formation

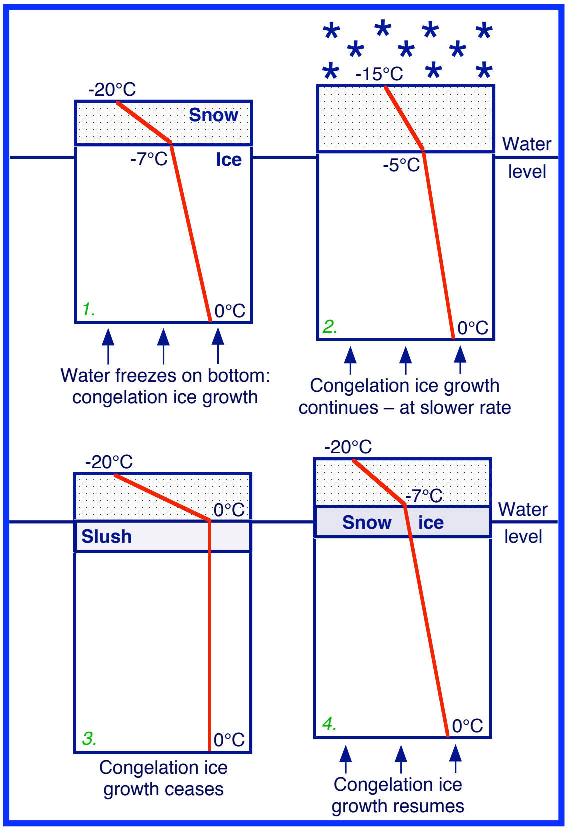
The evolution of a lake ice cover is seen in the schematic (right):

1. **Congelation** ice grows at the base of the ice cover as the latent heat of freezing is conducted to the atmosphere through the ice and snow because there are temperature gradients.

2. Snow accumulates and congelation ice growth rates decrease because the temperature gradients decrease.

3. The snow load exceeds the buoyancy of the ice; the ice surface is depressed below water level; the base of the snow cover is soaked as water flows up through cracks in the ice; congelation ice growth ceases because there is no temperature gradient in the ice.

4. Heat conduction through the snow cover continues; the slush freezes completely to form a layer of **snow ice** on top of the ice cover; congelation ice growth resumes.



Chena River, Fairbanks, AK (1 November 2006). The gray area, indicated by the arrow, is flooded snow (slush) on the ice cover. This will refreeze into ***snow ice***. (Photograph: Martin Jeffries)

Black (congelation) and White (snow) Ice

Ice Cover and Ice Cores

These examples of black and white ice cores are from lake ice; river ice would look much the same.

The top image in this pair shows black (white arrow) and white (orange arrow) ice on MST Pond, Poker Flat Research Range, AK, early in the freeze-up season.

Ice cores were drilled out of a number of lakes in the spring of 2000 (bottom image). The cores have been laid out on black plastic. The white ice at the top of the ice cores (orange arrow) and black ice (white arrow) are clearly visible. (Photographs: Martin Jeffries)

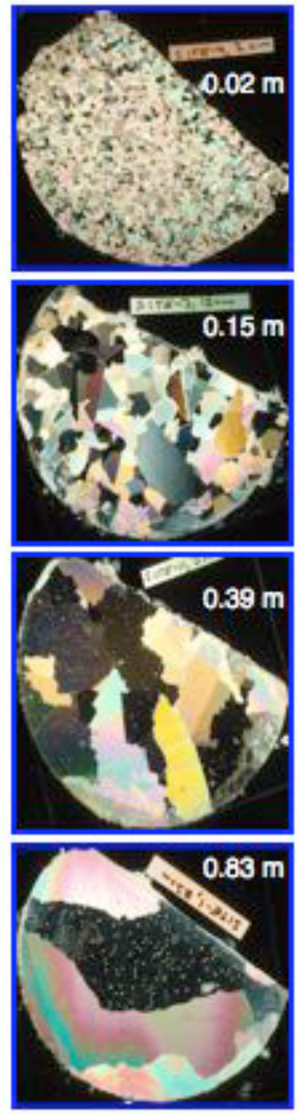
Ice cores, Poker Flat, April 2000

Thin Sections from Ice Cores

Thin sections are made by cutting ice cores vertically (below) or horizontally (right) into very thin layers. These layers allow light to pass through them. When thin sections are placed between cross-polarizing filters on a light table the, the individual ice crystals are revealed.

(Photograph: Martin Jeffries)

This vertical thin section reveals the white ice (orange arrow) at the top of the core and black ice (white arrow) at the bottom of the core. The white ice contains a large number of densely packed air bubbles and small ice crystals that cause strong light scattering. Note the column-like structure of the black ice.



(Photographs: Martin Jeffries)

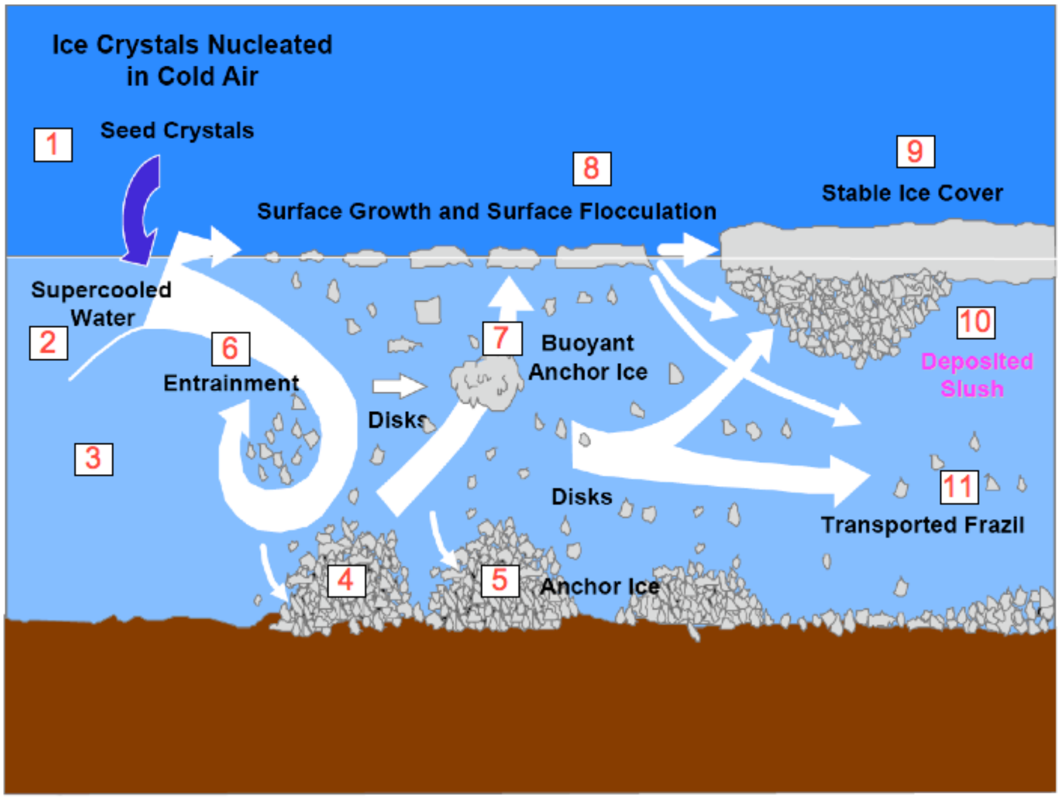
These horizontal sections show the dense crystal structure of the white ice (top) and the decreasing crystal density (or increase in crystal size) with depth of the black ice (0.15–0.83 m).

Frazil Ice

Frazil (or frazil crystals; also called needle ice) consists of ice crystals, platelets or discs, roughly 1 mm in diameter, that form in supercooled water that is too turbulent to permit the formation of sheet ice. **Supercooled water** is liquid water at a temperature below the freezing point (0°C) (Source: http://amsglossary.allenpress.com/glossary/). It is the product of a very rapid rate of surface heat loss.

Frazil Ice Formation

The schematic below shows the formation and evolution of frazil.



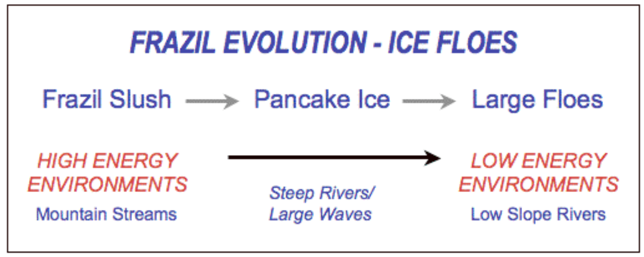
(Source: CRREL)

1) Frazil ice usually forms on clear nights when the weather is cold with air temperature ≤6°C.
2) These atmospheric conditions can lead to the formation of supercooled water.
3) Frazil crystals form spontaneously throughout the flow depth in supercooled, turbulent water.
4) Frazil crystals are so tiny that turbulent eddies in the water can carry them to the bottom. At this point in the frazil ice evolution, one of two things can happen (see 5 and 6).
5) Because the water is supercooled, frazil crystals will freeze onto any object they come into contact with and may adhere to the river bed and accumulate to form "anchor" ice.
6) Frazil crystals that are entrained (re-suspended) in the water column stick to each other to form groups of crystals, i.e., they flocculate (cluster) to form frazil slush, clusters or flocs.
7) Eventually the clusters and flocs are big and buoyant enough to overcome the water turbulence and rise to the surface.
8) The portion of the slush at the water surface, clusters and flocs freeze together to form pancakes (a few centimeters to a several meters in diameter).
9) As the water surface continues to lose some of its heat to the atmosphere, this pancake ice freezes together to form a continuous ice cover.
10) Frazil crystals can also accumulate beneath other floating ice in the river.
11) In very turbulent water, frazil crystals can be transported downstream until they encounter a barrier or the water turbulent decreases and they rise to the water surface.

(Sources: New Brunswick River Ice Manual, University of Alberta. Engineering, Frazil Ice - http://en.wikipedia.org/wiki/Frazil_ice, Hydrowiki - http://www.hydrowiki.psu.edu/wiki/index.php/Frazil_Ice)

Frazil Ice, Pancake Ice and Ice Floes

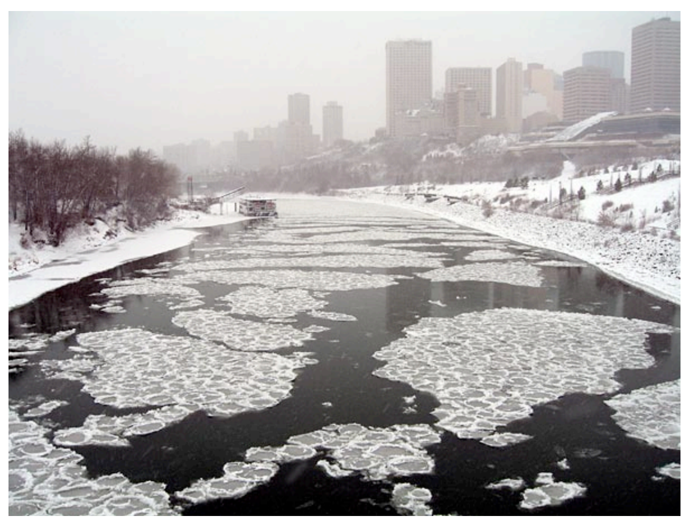
The diagram (right) shows the general forms of frazil (slush, pancake, floe), the conditions under which they form and likely environments to find them in.



Pancake ice is roughly circular accumulations of frazil ice, usually less than about 3 m in diameter, with raised rims caused by collisions (Source: http://amsglossary.allenpress.com/glossary/). These can freeze together into large **ice floes**.

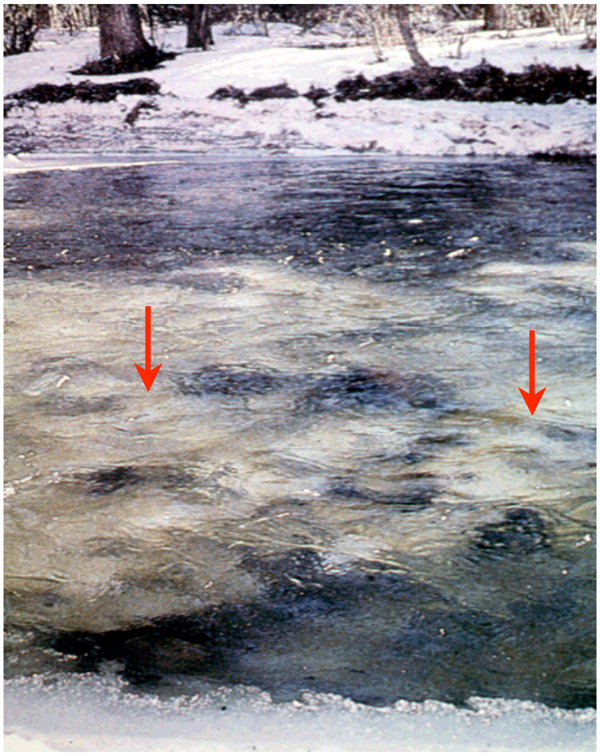
Frazil ice flocs (loose clumps of ice indicated by the orange arrow) and pancake ice (white arrow) on the Chena River AK, 25 October 2006. (Photograph: Martin Jeffries)

Frazil ice pancakes on the Chena River AK, 25 October 2006. The upturned edges on some of the floes are a consequence of the floes colliding with each other. (Photograph: Martin Jeffries)



Ice floes, made up of smaller pancakes, on the North Saskatchewan River, Edmonton, Alberta, Canada. (Photograph: J. Darragh in the Guardian Unlimited, 2007)

Anchor ice visible on the riverbed during spring break-up (indicated by arrows).



(Source Photo: CRREL River Ice guide and Glossary)

Anchor ice is ice attached to the beds of streams and lakes (*photograph at left*). It develops in supercooled water if turbulence is sufficient to maintain uniform temperature at all depths, in which case a spongy mass of frazil accumulates on objects exposed to rapid flow, and later deposition fills in the pores and creates solid ice. When the water temperature increases to above 0°C (in the spring), the ice rises to the surface, often carrying with it the object on which it had accumulated (Source: http://amsglossary.allenpress.com/glossary/).

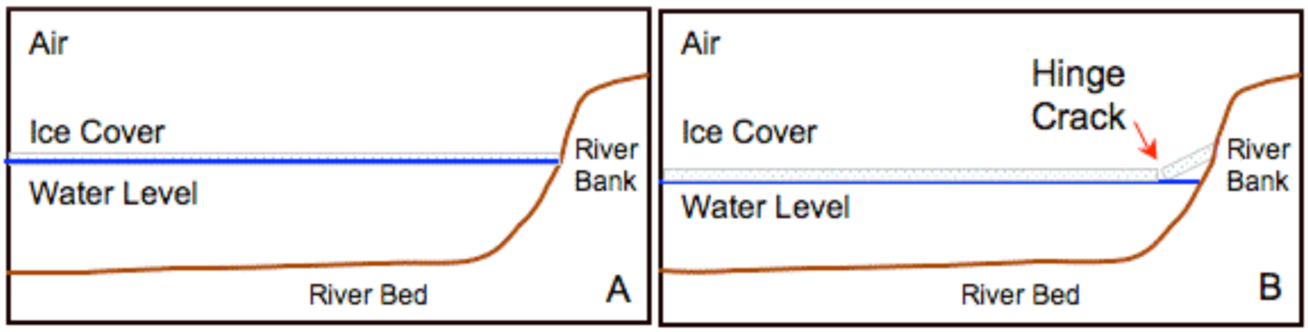
Anchor ice mass collected from the bed of Lake Michigan, near Chicago, IL. The ice mass is formed from delicate, interlaced ice crystals and is about 40 cm in diameter. (Source: http://faculty.gg.uwyo.edu/kempema/)

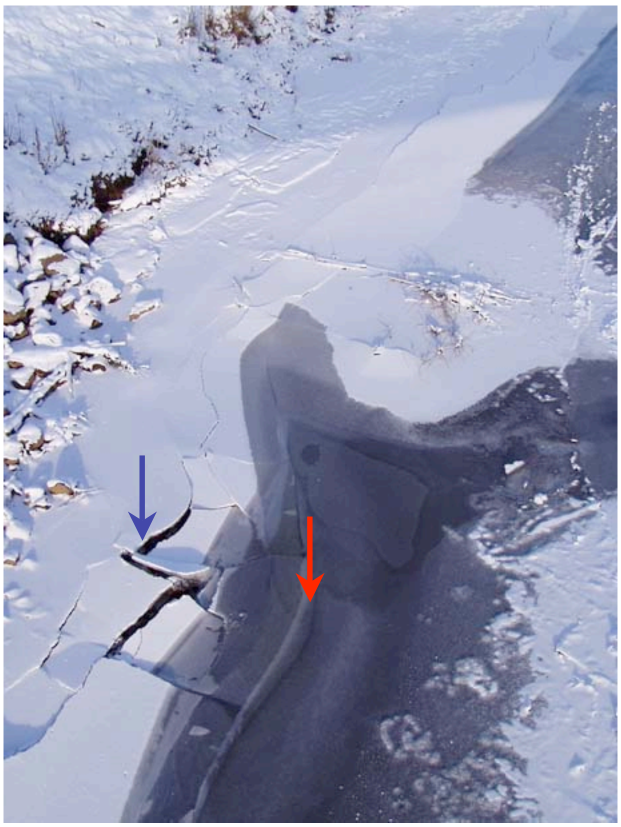
Other Features in River Ice

Hinge Cracks and Dropped Ice

A **hinge crack** is a crack caused by significant changes in water level (Source: http://www.expertglossary.com/). Hinge cracks can form in thin fall ice cover.

The schematic below illustrates the development of a hinge crack. The river ice grows at the top of the water column and floats on top of it (A). As the source of inflow into the lake decreases due to the freeze-up of streams and precipitation falls as snow rather than rain, the level of the lake falls. If the ice cover is not attached to the bank, i.e., free-floating, it is structurally unaffected by the decreasing lake water level. However, if the thin ice is frozen to the bank, it breaks because there is no longer any water to support it and it is to thin/weak to support the snow load. This is a hinge crack (B).




(Photograph: Martin Jeffries)

The initial, thin autumn ice cover is not very strong. This means that the ice is prone to failure when underlying water does not support it. This leads to the creation of a hinge crack. The blue arrow indicates the hinge crack in the image at left. Note how thin the ice is. The failure of the ice cover maybe sufficient to break it into pieces.

These ice pieces may become flooded (orange arrow). This could happen because the ice cover cracks but does not break and water is forced up through the cracks onto the ice forming slush on the ice surface. When breaking, the ice pieces might become wedged in the remaining ice cover in such a way that they are not “free floating” and are below the water level resulting in flooding.

River Ice Modification – Breakage and Movement
Border ice on the Chena River AK that has fractured, broken and moved with the current on 9 November 2006.


(Photograph: Martin Jeffries)

River Ice Modification – Flooding
The ice cover can be flooded at any time during the freeze-up process.

The weight of the accumulated snow at the edge of the channel has depressed the ice cover below the water level. This cause the border ice to become flooded (Chena River AK, 1 November 2006).

(Photograph: Martin Jeffries)

15 November 2007 (13:54 – AST). Most of the border ice on the Nenana River, AK appears grey in color (orange arrow). This grey area is either bare, wet ice or slush (completely soaked snow) on the ice.

15 November 2007 (14:55 – AST). This photograph was acquired about one hour after the one above. It has snowed and the formerly bare ice now appears "whiter" (arrow). The heterogeneous tones of the snow cover indicate that the ice cover was wet and the snow is experiencing varying degrees of wetness. This wet snow will eventually freeze into white (snow) ice.

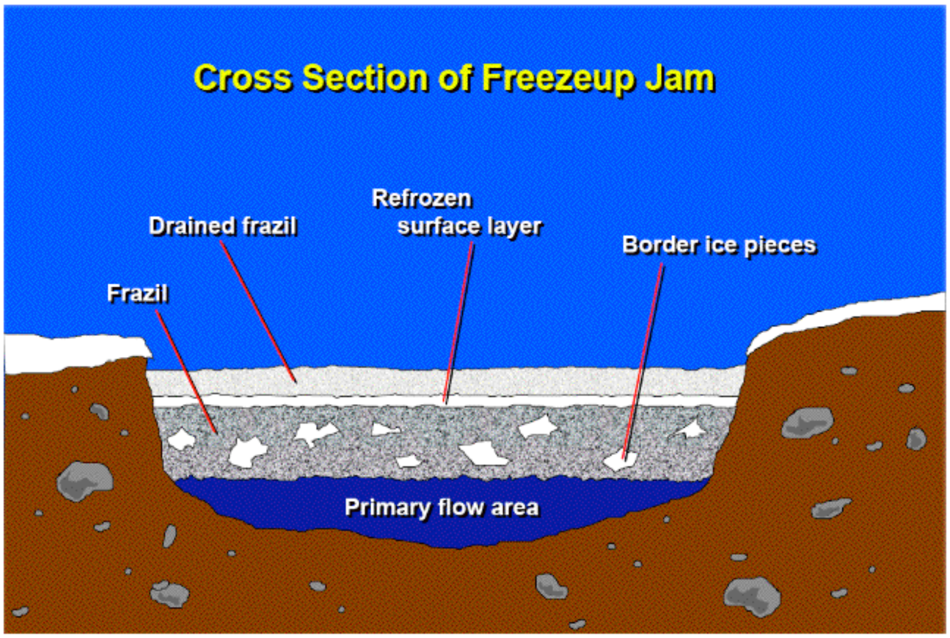
(Photographs: Nan Eagleson)

Freeze-Up Ice Jams

A **freeze-up ice jam** is an accumulation of broken river ice caught in a narrow channel. Ice jams during freeze-up are quite porous (Source: http://amsglossary.allenpress.com/glossary/).

Ice jams occur at locations where the river is unable to continually move the ice. This may occur in the vicinity of a sharp bend, a decrease in channel slope, at constrictions in the river or at the confluence of two or more rivers (Source: CRREL).

Freeze-up jams form in early to mid-winter. They are comprised of frazil and broken and border ice. They are unlikely to release during the winter; therefore, the water flow is fairly steady until spring break-up (Source: CRREL).



The diagram above shows the general structure of a freeze-up ice jam (Source: CRREL).

This is an example of a freeze-up ice jam (Source: CRREL).

Leads

Sheet ice can be defined as a smooth, continuous ice cover formed by freezing in place or by the arrest and juxtaposition of ice floes in a single layer (Source: CRREL).

In sea ice terminology, a **lead** (pronounced “leed”) is defined as a transient area of open water within the sea ice cover that arises through the dynamical effects of oceanic and atmospheric stresses, such as tides, acting to pull the sea ice floes apart (Source: http://www.esr.org/outreach/glossary/leads.html).

Here, the meaning of **lead** as used by local people in central Alaska is adopted. On a river, the term lead refers to a transient open water area that takes much longer to freeze over than the rest of the river ice. It can remain open for days and sometimes weeks after the rest of the river ice cover has formed. These may be zones of higher water velocity that take longer to freeze over than the adjacent slower water zones. These will be the zones of thinnest ice on the river and may be a hazard to people using the river as a winter transportation route.

The series of images below shows the freeze-up of a lead in the ice cover on the Nenana River, AK
(Photograph: N. Eagleson, Denali Education Center).


12 December 2007


14 December 2007


17 December 2007


18 December 2007

Aufeis

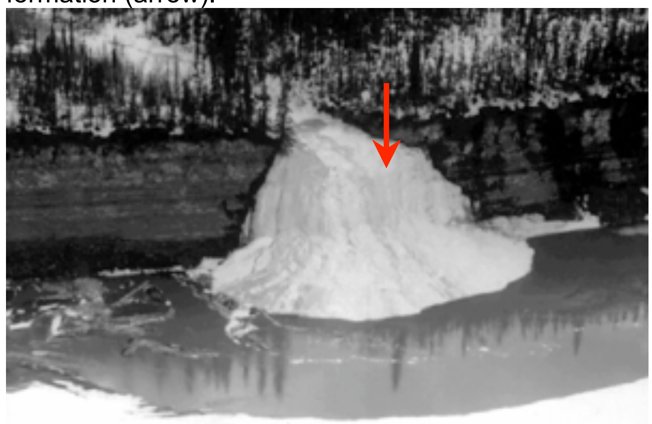
Aufeis (pronounced “off ice”) is the ice that forms in arctic and sub-arctic stream and river valleys during the winter when water from a spring or stream emerges and freezes on top of previously formed ice. Aufeis forms by upwelling of river water behind ice dams or by ground-water discharge (springs). During winter, the freezing of the successive ice layers can lead to aufeis accumulations several meters thick. As a consequence, it often extends above the summer water level and so is stranded above the main channel of the stream or river long after main channel has melted out. Melting aufeis can contribute water to the drainage system well into the summer.

(Source: http://amsglossary.allenpress.com/glossary/ and http://www.nationmaster.com/encyclopedia/Aufeis)

Aufeis stranded above the channel of a creek near Fox AK, July 2006.

(Photograph: Martin Jeffries)

Spring water from the bank has flowed onto the main channel of the river and frozen into an aufeis formation (arrow).



(Source: NOAA-NWS)

River Ice Break-up

River ice break-up is the disintegration of an ice cover on land, river, or coastal waters as a result of thermal (meteorological) and mechanical (hydraulic) processes. The break-up of a particular ice cover depends on its thickness and the relative importance of each of these processes. (Source: http://amsglossary.allenpress.com/glossary/ and U. of Alberta, Engineering).

Break-up begins with snowmelt. **Snowmelt** is the water resulting from the melting of snow, including the snow on the ice and on the riverbank.

Thermal Break-Up

A **thermal break-up** is initiated when the air overlying the ice warms to above freezing (>0°). In this kind of break-up, the ice appears to "rot" in situ (in place). The snowmelt reduces the surface albedo of the river in two ways: it exposes the black ice and the snowmelt ponds on the ice surface. As open water areas form and grow (low albedo) more energy is introduced into the melting process. In additions, more ice surface area becomes available for melting as the ice breaks up (in place) into discrete blocks: melting can now occur on the top, bottom and sides of these ice blocks. The rate of thermal deterioration accelerates as surface albedo decreases further. (Source: U of Alberta, Engineering)

On-ice Channels/Open Water Channels

On-ice channels are linear features on the ice cover, located parallel to the riverbank, that are formed when snowmelt ponds on the ice cover. The channels along either bank are similar to a **moat** on a pond or lake.

Eventually, the on-ice channel water melts through the ice cover to from an open water channel. When the river ice temperature becomes isothermal at the melting point (ice cover is 0°C from top to bottom) it can be melted from above by the warm air and from below by the liquid water. These channels along either bank are similar to a moat on a pond or lake.

The remainder of the ice may melt in place or break-up into blocks and be moved downstream by the river current.

Snowmelt pools into channels (orange arrow) on the ice surface parallel to the riverbank (Circle, AK) (Source: http://www.ak-prepared.com/riverwatch2001/Riverwatchphotos.htm)

These channels of open water have formed on either side of the Innoko River at Shageluk, AK, 6 May 2008. (Photograph: J. Hamilton)

Lead Ice Melt-out
By the end of winter, most rivers are completely covered by sheet ice. **Sheet ice** defined as a smooth, continuous ice cover formed by in situ freezing or by the arrest and juxtaposition of ice floes in a single layer (Source: CRREL). On rivers, sheet ice may grow to "fill in" areas between already existing ice.

The time series of images that show the break-up of the Nenana River near Healy, AK. (All photographs: Mark Martin)

18 April 2008 – A small, open water zone has developed where a lead was located during freeze-up. The thinnest ice would have been located here.

25 April 2008 – The lead expands through thermal processes (vertical and lateral ice melting). The thinning ice appears to undergo some localized flooding (arrows).

30 April 2008 – The open water zone has expanded further.

4 May 2008 – The main channel is completely clear of ice. Ice remains on the riverbank and on gravel bars. Note that all of the snow has melted off the hills.

Rotten ice is any piece, body, or area of ice that is in the process of melting or disintegrating. It is characterized by a honeycomb structure, weak bonding between crystals, or the presence of melt water between grains (Source: http://amsglossary.allenpress.com/glossary/).

Candle ice is a form of rotten ice. It is disintegrating river or lake ice consisting of ice prisms or cylinders oriented perpendicular to the original ice surface; these "ice fingers" may be equal in length to the thickness of the original ice before its disintegration (Source: http://amsglossary.allenpress.com/glossary/). Candle ice is formed when black ice melts in place; melting occurs along crystal boundaries perpendicular to the ice surface.

The long crystals of candle ice have the appearance of bundles of needles or "candles" hence its name. (Photograph: Martin Jeffries)

An aerial view of "in place" melting of river ice including candle ice (Source: NOAA-NWS)

A view of "in place" melting of river ice including candle ice (Source: NOAA-NWS)

Mechanical Break-Up

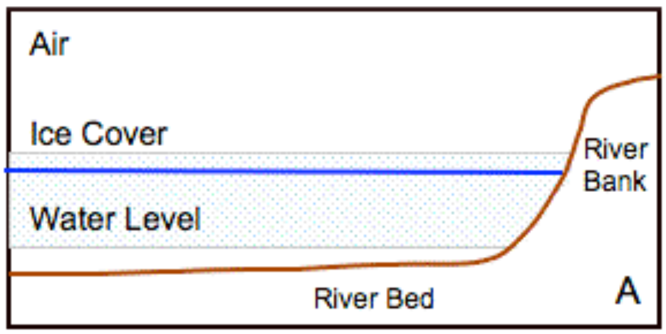
A **mechanical break-up** is dominated by hydraulic factors. These are linked to significant changes in the water level that are associated with a large snowmelt runoff event. Before significant thermal deterioration has occurred, the ice cover is lifted by a rapid increase in water level and it breaks into discrete pieces. Subsequently, the ice sheets and ice floes are carried downstream by the floodwater where an ice jam could form. (Source: U of Alberta, Engineering)

Hinge Cracks and Ice Cover Tipping

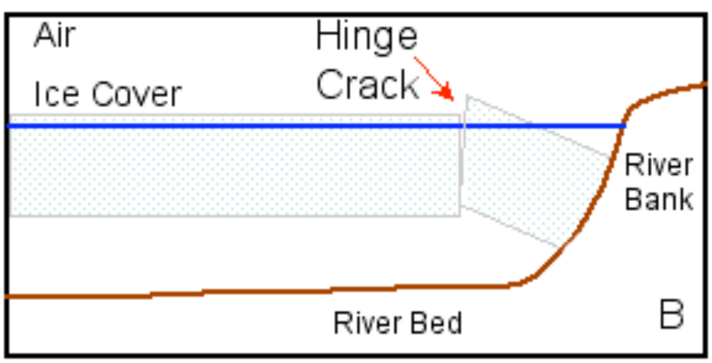
A **snowmelt flood** is a substantial rise in stream or river discharge caused by snowmelt runoff (Source: http://amsglossary.allenpress.com/glossary/). A large volume of water from snowmelt can also cause a sudden rise in the water level of a pond or lake.

A **hinge crack** is a crack caused by significant changes in water level (Source: http://www.expertglossary.com/weather/definition/hinge-crack). When a hinge crack forms in the spring ice cover, the floating ice is free to move in response to environmental forces (wind and currents).

Spring snowmelt can cause the water level in the pond can rise dramatically. The lake ice floats on top of the water.



If the ice cover is not anchored to the river bed or bank, it will freely rise with the increasing lake water level. However, if the ice is frozen to the riverbed (in shallow areas), the floating portion of the ice cover will flex and break forming a hinge crack.



A hinge crack in the ice cover on a river during spring break-up. In this case, the stream is very narrow and the hinge crack has formed in the middle of the channel.
(Source: New Brunswick River Ice Manual)

Transverse Cracks and Ice Floes
When the water level changes significantly, the ice cover is pushed higher or lower, causing it to break into pieces. A stage (water level) increase of 1.5 to 3 times the thickness of the ice is needed to lift, break and transport the ice cover.

A **transverse crack** is a crack that is nominally perpendicular to the riverbanks. Transverse cracks have a regular along-river spacing of approximately 1000 times the thickness of the solid ice cover. (Source: U. of Alberta, Engineering and NOAA-NWS).

Once the ice begins to move downstream, the very large ice expanses can collide with each other and the banks causing further breakage of the ice cover into ice floes.

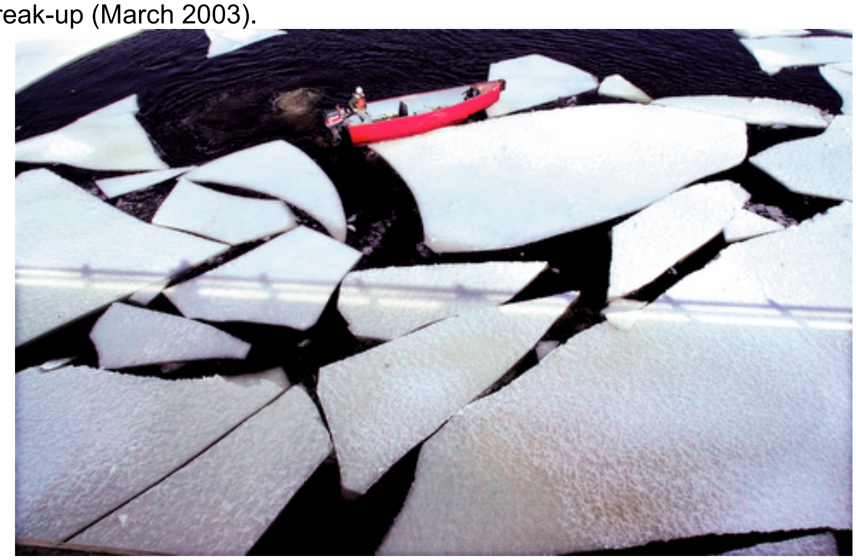
The transverse cracks have formed in this river ice cover making it possible for ice to move downstream with the river current.

(Source: NOAA-NWS)

Spring break-up on the Chena River, AK. The ice cover has broken up into small to medium floes which are moving downstream with the current.

(Source: http://www.iarc.uaf.edu/gallery/main.php?g2_view=core.ShowItem&g2_itemId=908)

A small skiff among large ice floes on the Kennebec River, ME, during break-up (March 2003).

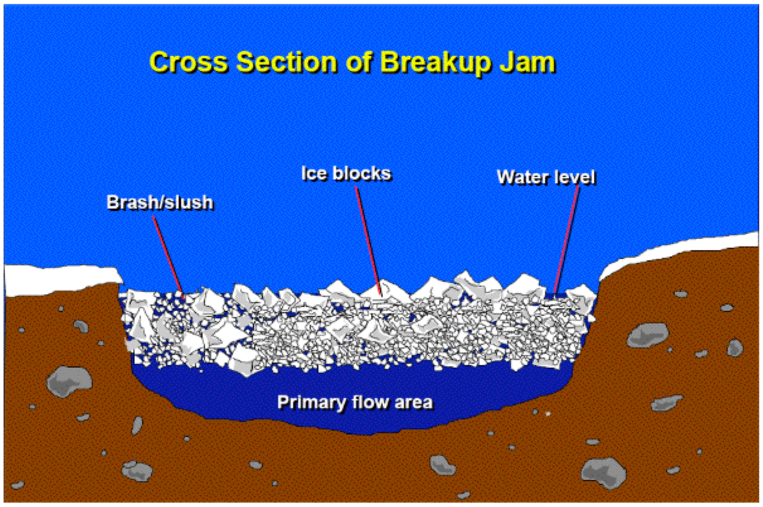


(Photo: David Learning – Source: http://www.centralmaine.com/blogs/outdoors/cat_natural_world.html)

Break-Up Ice Jams

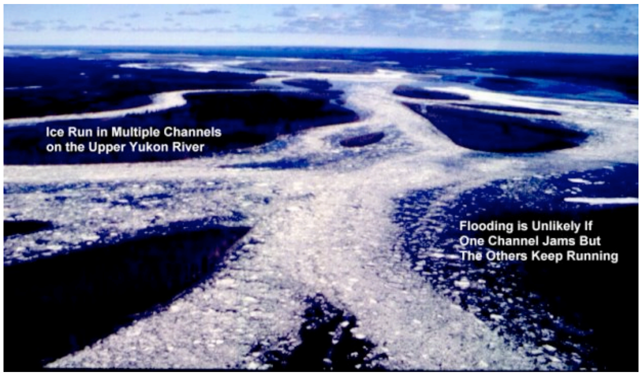
A **break-up ice jam** is an accumulation of broken river ice caught in a narrow channel. Break-up ice jams may comprise solid flows, frequently producing local floods during a spring breakup (http://amsglossary.allenpress.com/glossary/). Ice jamming develops when prolonged sub-freezing (<0°C) weather is followed by significant warming, allowing the ice on rivers to break free and flow downstream (Source: http://www.wrh.noaa.gov/tfx/hydro/FAW/fawflooding.php?wfo=ggw).

Break-up jams form in mid to late winter. A jam may form more than once per year. They are comprised of broken sheet and border ice and are highly unstable and release suddenly. The sudden release may result in a highly unsteady water flow (surges) (Source: CRREL). The severity of an ice jam event is generally influenced by: river flow, volume and strength of river ice, length of the breakup period, rate of heat transfer, snow depth, and precipitation. Of these, river flow is the single most important determinant of ice jam severity (Source: New Brunswick River Ice Manual).



This diagram shows the general structure of a break-up ice jam (Source: CRREL).

Aerial view of an ice jam that is caused by a bend in the river. The arrow indicates the location of the ice jam. (Source: NOAA-NWS)



Aerial view of an ice jam that is caused by the confluence of several rivers. (Source: NOAA-NWS)

Ice Jams, Flooding and Stranded Ice

Ice jams develop when prolonged sub-freezing (<0°C) weather is followed by significant warming, allowing the ice on rivers to break free and flow downstream (Source: http://www.wrh.noaa.gov/tfx/hydro/FAW/fawflooding.php?wfo=ggw).

Break-up begins with snowmelt. **Snowmelt** is the water resulting from the melting of snow. Much of this water drains onto the river system. A **snowmelt flood** is a substantial rise in stream or river discharge caused by snowmelt runoff (Source: http://amsglossary.allenpress.com/glossary/). This water pulse may be increased by spring rain events (Source: http://www.wrh.noaa.gov/tfx/hydro/FAW/fawflooding.php?wfo=ggw). This water can be dammed behind an ice jam; this can lead to upstream flooding (water only). In time, the ice jam weakens and breaks. This leads to significant amounts of water and ice moving downstream. In some cases, this water overtops the riverbanks carrying large pieces of ice with it and causing significant damage. When the water retreats, ice blocks are stranded on land and eventually melt in place.

A house surrounded by floodwater and ice.
(Source: New Brunswick River Ice Manual).

A house in the floodplain surrounded by ice after the floodwaters have retreated (Tunbridge, VT, March 1999) (Source: CRREL).

A breakup ice jam on the Lamoille River caused major flood damage In the village of Hardwick, VT, in February 1981(Source: CRREL).

Resources

These Alaska Lake Ice and Snow Observatory Network (ALISON) web pages provide some basic water and ice background:

- Background – Lake Ice Science: http://www.gi.alaska.edu/alison/ALISON_objective3.html
- Lake Ice And Snow Science: Why Study Lake Ice and Snow? Changes in Freshwater Ice http://www.gi.alaska.edu/alison/ALISON_SCIENCE_ChangeLakes.html
- Lake Ice and Snow Science – Basic Concepts: H_2O Phase Diagram http://www.gi.alaska.edu/alison/ALISON_SCIENCE_BConcepts.html
- Lake Ice and Snow Science – Basic Concepts: Hydrological Cycle
- http://www.gi.alaska.edu/alison/ALISON_SCIENCE_BC_H2OCycle1.html
- Lake Ice and Snow Science – Basic Concepts: Thermal Conductivity
- http://www.gi.alaska.edu/alison/ALISON_SCIENCE_BC_ThermCon.html
- Lake Ice and Snow Science – Basic Concepts: Albedo
- http://www.gi.alaska.edu/alison/ALISON_SCIENCE_BC_Albedo.html

The American Meteorological Society Glossary of Meteorology
http://amsglossary.allenpress.com/glossary

Climate Change Project Jukebox - http://uaf-db.uaf.edu/jukebox/ClimateChange/htm/sam.htm#top
Samuel Demientieff's talk at the Annual OLGC Teachers Meeting December 2003 in Fairbanks has some pictures, definitions and observations about Global Change.

CRREL River Ice Guide and Glossary http://www.crrel.usace.army.mil/ierd/ice_guide/iceguide.htm

CRREL Ice Jam Database http://www.crrel.usace.army.mil/ierd/icejam/icejam.htm

Earth and Space Research http://www.esr.org/outreach/glossary/leads.html

Expert Glossary http://www.expertglossary.com/science

National Weather Forecast Office (Great Falls, MT) - River Ice and River Ice Processes,
www.wrh.noaa.gov/tfx/hydro/IJAD/RiverIceTypes.php

Nature Watch - Ice Watch: volunteer lake and river monitoring program in Canada.
http://www.naturewatch.ca/english/icewatch/

The Nenana River Project http://www.gi.alaska.edu/river_ice/

NOAA-NWS Alaska-Pacific River Forecast Center
http://aprfc.arh.noaa.gov/resources/docs/brkup.php

New Brunswick River Ice Manual - http://www.gnb.ca/0009/0369/0004/index-e.asp.)

River Lake Ice Engineering, George D. Ashton (1986}

University of Alberta, Faculty of Engineering: An Introduction to River Ice Processes (Dan Healy) -
http://courses.civil.ualberta.ca/cive433/Intro_to_Ice_6.pdf

Ice Seasonality Investigation

Lake Ice Glossary

pages

It is important to keep in mind that even moderately sized ponds rarely freeze to the bottom. Even during the coldest part of the winter there is some water below the ice at the deepest parts of the pond.

Some Key Concepts and Terms

Some Properties of Water

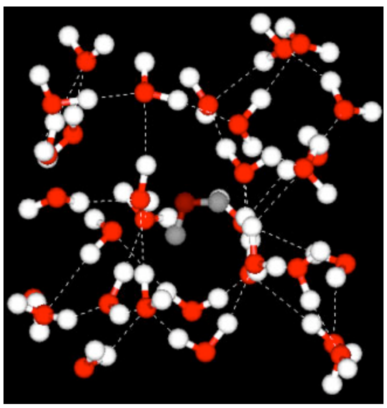
Water can exist in any one of three states: solid (ice), liquid (water) and gas (water vapor).

Fresh water has a maximum density at around 4°C: 1 g cm^3, 1 g ml^{-1}, 1 kg $liter^{-1}$, 1000 kg m^3, or 1 tonne m^3.

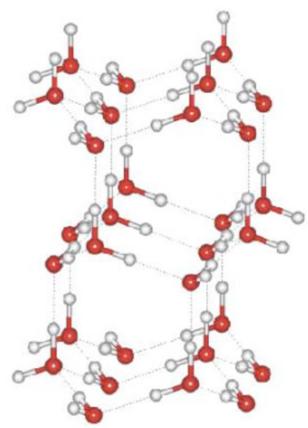
Water is the only substance where the maximum density does not occur when solidified (which is why ice floats on water)..

Solid water (ice) is the most ordered (least energetic) state of water while gas is the least ordered (highest energetic) state.

Water Phase Change



Liquid water can be thought of as a seething mass of H_2O molecules in which hydrogen-bonded clusters are continually forming, breaking apart, and re-forming. The more crowded and jumbled arrangement in liquid water can be sustained only by the greater amount thermal energy available above the freezing point (0°C).
(Source: http://ssrl.slac.stanford.edu/nilssongroup/pages/project_liquid_structure.html)

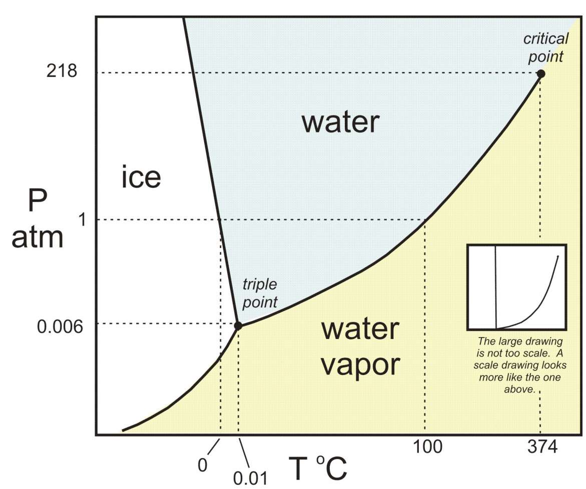


Notice the *greater openness* of the ice structure. This is necessary to ensure the strongest degree of hydrogen bonding in a uniform, extended crystal lattice. (Source: http://ssrl.slac.stanford.edu/nilssongroup/pages/project_liquid_structure.html)

A **phase change** is a change from one state to another without a change in chemical composition. These changes are induced by the effects of temperature and/or pressure:

The transitions are:
Solid-to-liquid transition - *melting*
Liquid-to-solid transition - *freezing*
Liquid-to-gas transition - *evaporation*
Gas-to-liquid transition - *condensation*
Solid-to-gas transition - *sublimation*
Gas-to-solid transition - *deposition*

(Source: http://serc.carleton.edu/NAGTWorkshops/petrology/teaching_activities_table_contents.html)



Energy, Temperature and Heat

Energy is defined as the capacity to do work (the amount of work one system is doing on another). There are two kinds of energy that are of interest here:

- Internal energy is defined as the energy associated with the random, disordered motion of molecules; it refers to the invisible microscopic energy on the atomic and molecular scale
- Kinetic energy is energy of motion. The kinetic energy of an object is the energy it possesses because of its motion.

Temperature measures the average kinetic energy of the particles in a substance. It measures the degree of heat (high energy) or cool (low energy) of a substance. Heat is defined as energy in transit.

Heat (internal energy) moves from a **high** temperature region to a **low** temperature region. This is called heat transfer.

Heat Transfer

Latent Heat

Latent heat is the energy required to change a substance from one state to another at constant temperature.

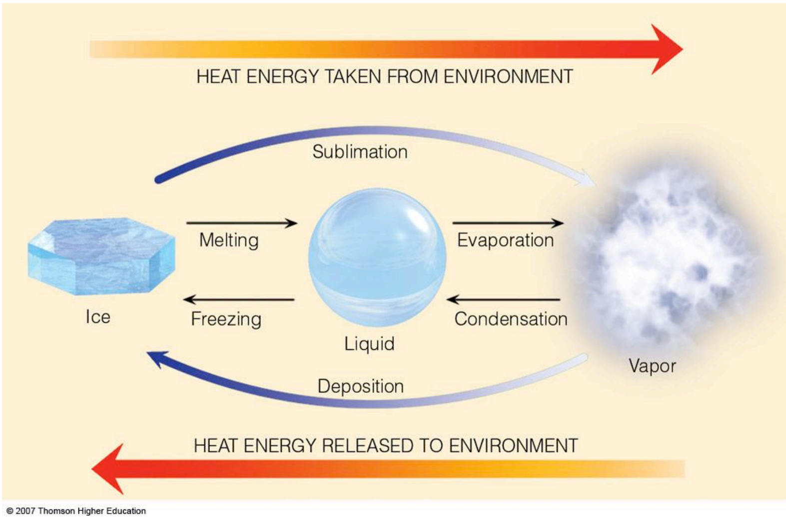
When a substance changes from one state to another, latent heat is added or released in the process.

LIQUID to VAPOR
Latent heat of evaporation is **taken** from the environment (about 540 cal per gram)

VAPOR to LIQUID
Latent heat of condensation is **released** to the environment

LIQUID to ICE
Latent heat of freezing is **released** to the environment (about 80 cal per gram)

ICE to LIQUID
Latent heat of fusion (melting) is **taken** from the environment

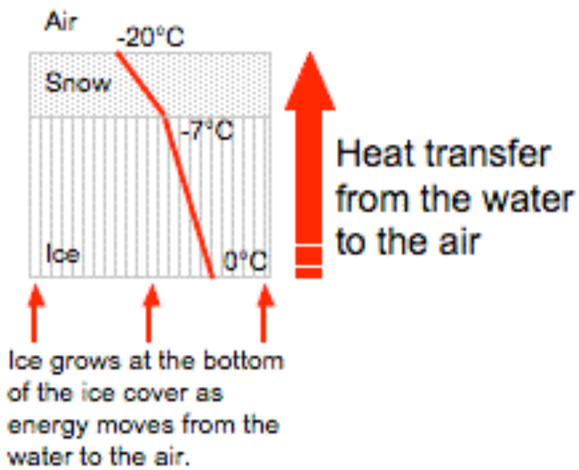


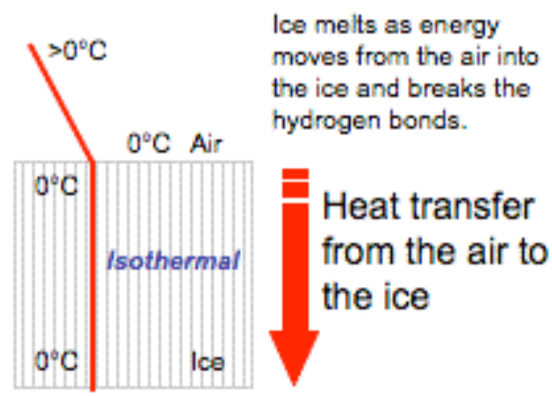
(Source: http://apollo.lsc.vsc.edu/classes/met130/notes/chapter2/lat_heat2.html)

Latent Heat of Freezing and Melting

The **latent heat of freezing** is the energy released from the water and added to the environment, in order for water to freeze into ice. When heat is subtracted from liquid water, the individual water molecules will slow down. They eventually slow to the point at which the hydrogen bonds do not allow the liquid to rotate anymore. Ice now develops. (Source: http://www.theweatherprediction.com/habyhints/19/)

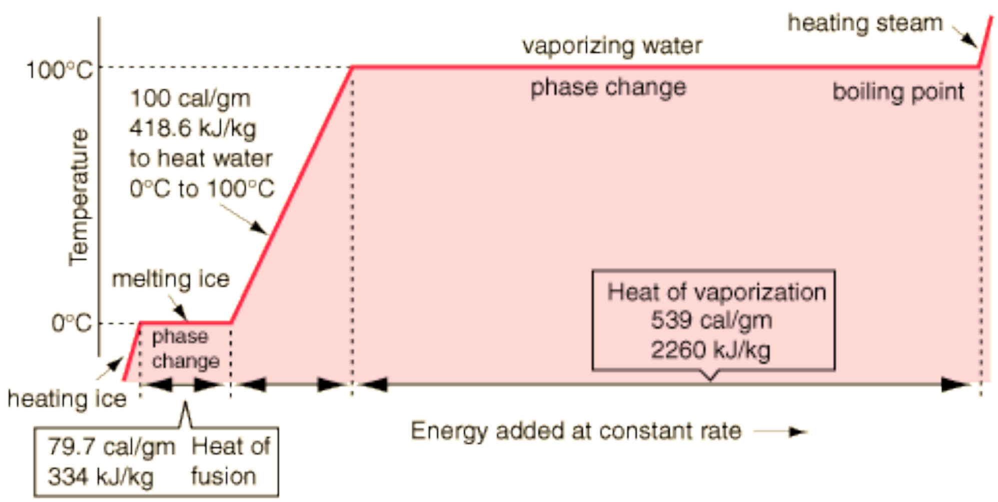
The **latent heat of fusion (melting)** is the energy that is taken from the environment and added to the ice to melt it into water. This energy is used to break the ice lattice bonds and allows the ice to go from a lower energetic state to a more energetic state (water). (Source: http://www.theweatherprediction.com/habyhints/19/)





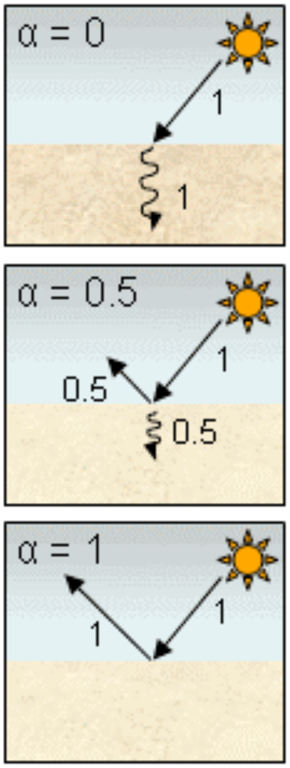
When water undergoes a phase change (a change from solid, liquid or gas to another phase) the temperature of the water stays the same. Energy is being used to either weaken the hydrogen bonds between water molecules or energy is being taken away from the water, which tightens the hydrogen bonds. When ice melts, energy is being taken from the environment and absorbed into the ice to loosen the hydrogen bonds. The temperature of the melting ice however stays the same until all the ice is melted. All hydrogen bonds must be broken from the solid state before energy can be used to increase the water's temperature.
(Source: http://www.theweatherprediction.com/habyhints/19/)

If heat were added at a constant rate to a mass of ice to take it through its phase changes to liquid water and then to steam, the energies required to accomplish the phase changes (the latent heat of fusion and latent heat of vaporization) would lead to plateaus in the temperature vs time graph.



(Source: http://hyperphysics.phy-astr.gsu.edu/Hbase/thermo/phase.html#c1)

Albedo



(Source: National Snow and Ice Data Center)

Albedo is a measure of reflectivity of a surface or body. It is the ratio of electromagnetic radiation (EM radiation) reflected to the amount incident upon it. The fraction, usually expressed as a percentage from 0% to 100% (or as a dimensionless value between 0 and 1), is an important concept in climatology and astronomy.

A **perfect absorber** does not reflect any of the sunlight that strikes it. It looks black and has an albedo of 0. When an object absorbs most of the light that hits it, it looks dark and has a low albedo.

A **perfect reflector** reflects all the sunlight that strikes it. It looks white and has an albedo of 1. Objects that reflect most of the light that hit them appear bright and have a high albedo.

Albedo Values for Common Earth Surfaces

Surface	**Albedo**
Absolute black surface	0.0
Forest	0.05-0.2
Water	0.06
Grassland and cropland	0.1-0.25
Dark colored soil surface	0.1-0.2
Dry sandy soil	0.25-0.45
Dry clay soil	0.15-0.35
Sand	0.2-0.4
Mean albedo of the Earth	0.36
Granite	0.3-0.35
Glacial Ice	0.3-0.4
Light colored soil surfaces	0.4-0.5
Dry salt cover	0.5
Tops of clouds	0.6-0.9
Fresh, deep snow	0.9
Absolute white surface	1.0

Lake Freeze-up

Freeze-up is the seasonal formation of a continuous ice cover on a body of water. An ice cover is a layer of ice on top of some other feature, usually the surface of a lake or pond (but also rivers and seas/oceans). (Source: http://amsglossary.allenpress.com/glossary/).

Meteorological factors such as air temperature, precipitation, wind speed and radiation balance coupled with physical characteristics of the lakes and ice (lake area, depth, volume and fetch (the distance of open water over which the wind blows); snow depth; ice thickness, type and albedo) lead to complex interactions and feedbacks that affect the timing of freeze-up and break-up (ice cover duration) each year.

New Ice

A **thermal ice cover** grows when ice crystals form on the surface and rapidly link together to create a thin ice sheet.

Sheet ice is ice formed in a "smooth" thin layer on a water surface by the coagulation of ice crystals through rapid freezing (Source: http://amsglossary.allenpress.com/glossary/). It is also defined as a smooth, continuous ice cover formed by in situ freezing or by the arrest and juxtaposition of ice floes (defined on p. 10) in a single layer (Source: CRREL). On ponds and small lakes, a complete ice cover can form overnight.

A new ice sheet that has formed overnight under clear, calm and cold weather conditions.
(Photograph: Martin Jeffries)

Individual ice crystals are visible in a new ice sheet.
(Photograph: Martin Jeffries)

Border ice is an ice sheet in the form of a long border attached to the bank or shore. It is also called shore ice. (Source: http://www.expertglossary.com/weather/definition/border-ice).

This is the first ice to form on the lake: it grows in calm water zones. As a consequence, the border ice may appear "whiter" than the younger ice because it is thicker and may have a thin snow cover.

In the image at right, the border ice appears more opaque (yellow arrow) than the new ice cover (red arrow).

(Photograph: Martin Jeffries)

Black (congelation) and White (snow) Ice

On small lakes two kinds of ice form, black (congelation) ice and white (snow ice).

Black ice or congelation ice is ice that appears dark in color because it permits significant light transmission to the underlying water (Source: http://amsglossary.allenpress.com/glossary/).

White ice or snow ice is ice with a white appearance caused by the occurrence of bubbles within the ice. It is formed from refrozen slush**.** The bubbles increase the scattering of all wavelengths of light in contrast to the appearance of bubble-free black ice (Source: http://amsglossary.allenpress.com/glossary/).

A **temperature gradient** is the temperature difference between two points divided by the distance between those points.

Black and White Ice Formation

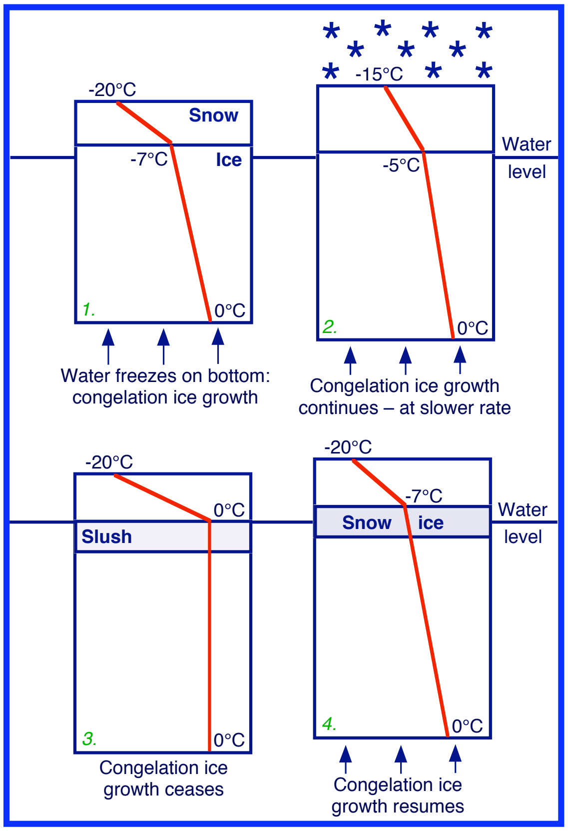
The evolution of a lake ice cover is seen in the schematic (right):

1. **Congelation** ice grows at the base of the ice cover as the latent heat of crystallization is conducted to the atmosphere through the ice and snow because there are temperature gradients.

2. Snow accumulates and congelation ice growth rates decrease because the temperature gradients decrease.

3. The snow load exceeds the buoyancy of the ice; the ice surface is depressed below water level; the base of the snow cover is soaked as water flows up through cracks in the ice; congelation ice growth ceases because there is no temperature gradient in the ice.

4. Heat conduction through the snow cover continues; the slush freezes completely to form a layer of **snow ice** on top of the ice cover; congelation ice growth resumes.



This image was acquired at 33.0 Mile Pond, AK (24 October 2004). The gray area, indicated by the arrow, is flooded snow (slush) on the ice cover. This will refreeze into ***snow ice.***
(Photograph: Martin Jeffries)

Black (congelation) and White (snow) Ice

Ice Cover and Ice Cores

The top image in this pair shows black (white arrow) and white (orange arrow) ice on MST Pond, Poker Flat Research Range, AK, early in the freeze-up season.

Ice cores were taken from a number of lakes in the spring of 2000 (bottom image). The cores have been laid out on black plastic. The white ice at the top of the ice cores (orange arrow) and black ice (white arrow) are clearly visible. (Photograph: Martin Jeffries)

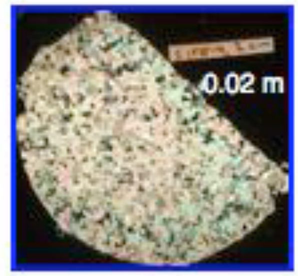
Ice cores, Poker Flat, April 2000

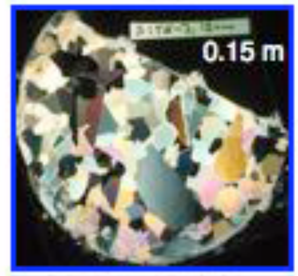
Thin Sections from Ice Cores

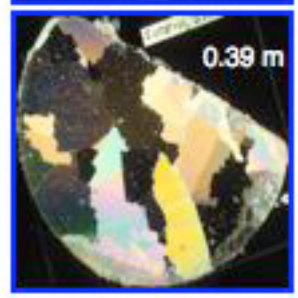
Thin sections are made by cutting ice cores vertically (below) or horizontally (right) into very thin layers. These layers allow light to pass through them. When thin sections are placed between cross-polarizing filters on a light table the, the individual ice crystals are revealed.

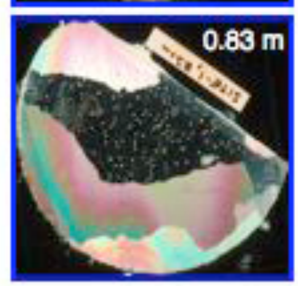
(Photograph: Martin Jeffries)

This vertical thin section reveals the white ice (orange arrow) at the top of the core and black ice (white arrow) at the bottom of the core. The white ice contains a large number of densely packed air bubbles and small ice crystals that cause strong light scattering. Note the column-like structure of the black ice.









(Photograph: Martin Jeffries)

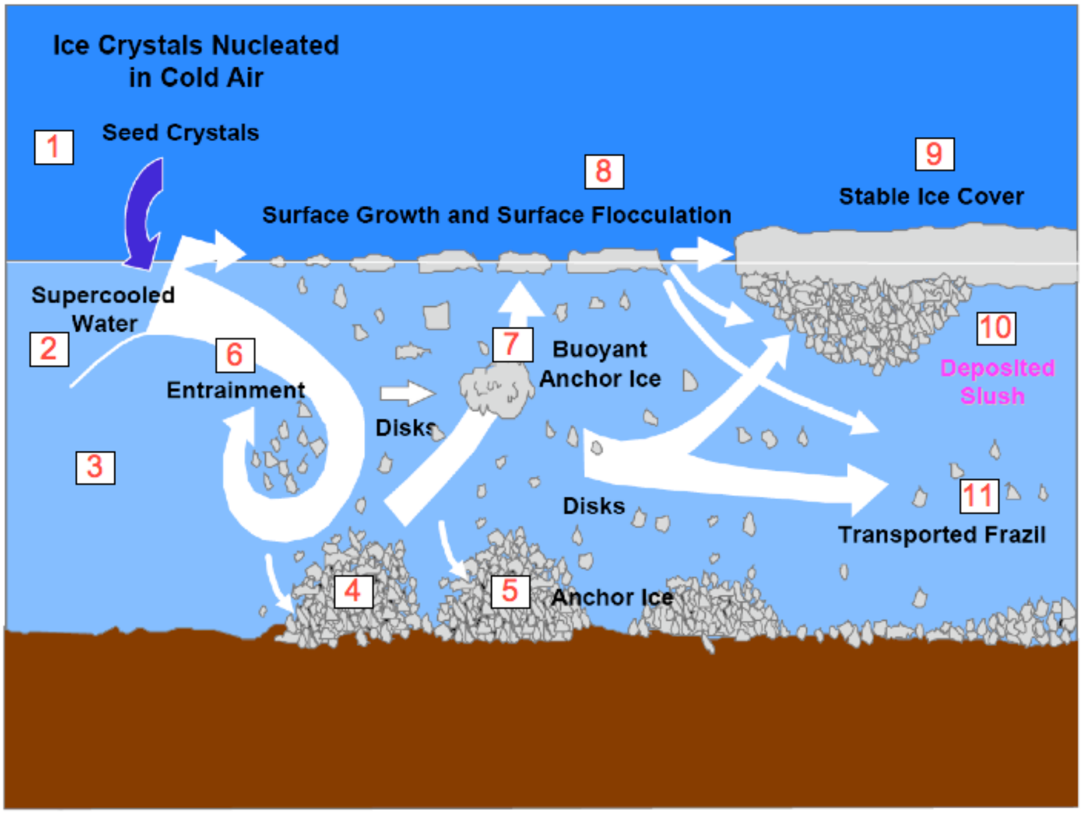
These horizontal sections show the dense crystal structure of the white ice (top) and the decreasing crystal density (or increase in crystal size) with depth of the black ice (0.15–0.83 m).

Frazil Ice

Frazil (or frazil crystals; also called needle ice) consists of ice crystals, platelets or discs, roughly 1 mm in diameter, that form in supercooled water that is too turbulent to permit the formation of sheet ice. **Supercooled water** is liquid water at a temperature below the freezing point (Source: http://amsglossary.allenpress.com/glossary/). It is the product of a very rapid rate of surface heat loss.

Frazil Ice Formation

The schematic below shows the formation and evolution of frazil.

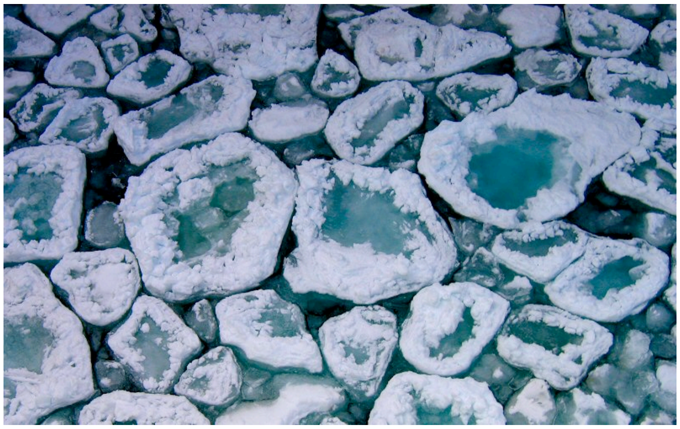


(Source: CRREL)

1) Frazil ice usually forms on clear nights when the weather is cold with air temperature ≤6°C.
2) These atmospheric conditions can lead to the formation of supercooled water.
3) Frazil crystals form spontaneously throughout the flow depth in supercooled, turbulent water.
4) Frazil crystals are so tiny that turbulent eddies in the water can carry them to the bottom. At this point in the frazil ice evolution, one of two things can happen (see 5 and 6).
5) Because the water is supercooled, frazil crystals will freeze onto any object they come into contact with and may adhere to the river bed and accumulate to form "anchor" ice.
6) Frazil crystals that are entrained (re-suspended) in the water column stick to each other to form groups of crystals, i.e., they flocculate (cluster) to form frazil slush, clusters or flocs.
7) Eventually the clusters and flocs are big and buoyant enough to overcome the water turbulence and rise to the surface.
8) The portion of the slush at the water surface, clusters and flocs freeze together to form pancakes (a few centimeters to a several meters in diameter).
9) As the water surface continues to lose some of its heat to the atmosphere, this pancake ice freezes together to form a continuous ice cover.
10) Frazil crystals can also accumulate beneath other floating ice in the river.
11) In very turbulent water, frazil crystals can be transported downstream until they encounter a barrier or the water turbulent decreases and they rise to the water surface.
(Sources: New Brunswick River Ice Manual, University of Alberta. Engineering, Frazil Ice - http://en.wikipedia.org/wiki/Frazil_ice, Hydrowiki - http://www.hydrowiki.psu.edu/wiki/index.php/Frazil_Ice)

Pancake Ice and Ice Floes

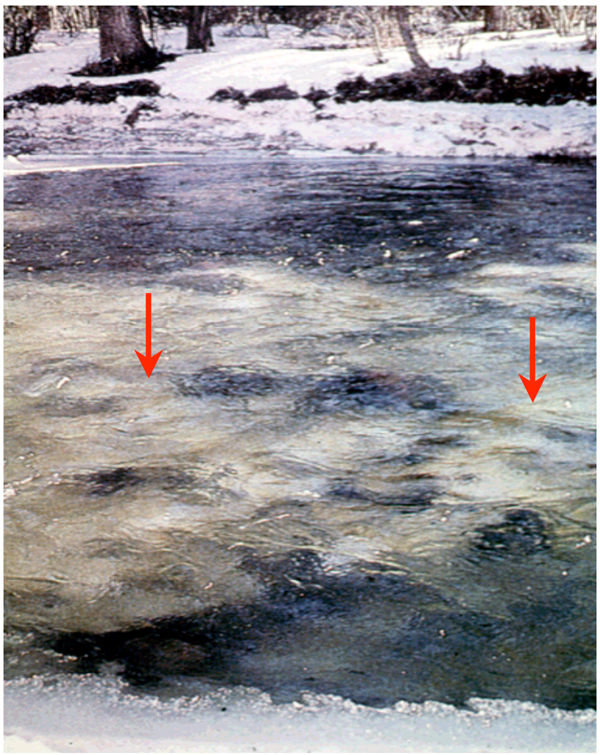
Pancake ice consists of roughly circular accumulations of frazil ice, usually less than about 3 m in diameter, with raised rims caused by collisions (Source: http://amsglossary.allenpress.com/glossary/). These can freeze together into large **ice floes**.



In large lakes, pancake ice and ice floes can form in much the same fashion as they do on the polar oceans. These are pancakes on Lake Superior.
(Source: http://www-personal.umich.edu/~jensenl/visuals/album/2006/ice/)

Some large lakes never freeze over completely, it is possible for ice floes to be driven together creating ice ridges such as on Avon Lake, OH, 12 February 2005 (red arrows). (Source: http://www.wunderground.com/)

Anchor ice visible on the riverbed during spring break-up (indicated by arrows).



(Source: CRREL River Ice guide and Glossary)

Anchor ice is ice attached to the beds of streams and lakes (*photograph at left*). It develops in supercooled water if turbulence is sufficient to maintain uniform temperature at all depths, in which case a spongy mass of frazil accumulates on objects exposed to rapid flow, and later deposition fills in the pores and creates solid ice. When the water temperature increases to above 0°C (in the spring), the ice rises to the surface, often carrying with it the object on which it had accumulated (Source: http://amsglossary.allenpress.com/glossary/).

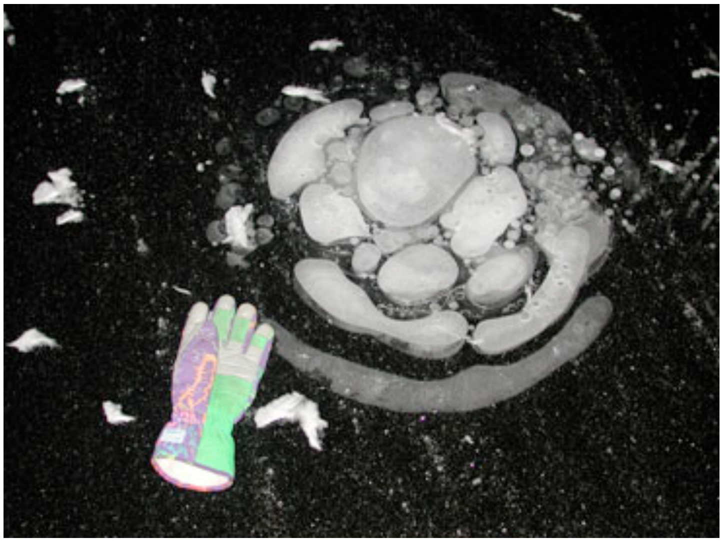
Anchor ice mass collected from the bed of Lake Michigan, near Chicago, IL. The ice mass is formed from delicate, interlaced ice crystals and is about 40 cm in diameter.
(Source: http://faculty.gg.uwyo.edu/kempema/)

Other Features in Lake Ice

Bubbles in Lake Ice
Air (gas) bubbles in water are generated by the action of breaking waves, the impact on water of spray droplets, and by biological processes. These may freeze into the lake ice. They range in size from some centimeters down to microns. Small bubbles in particular can be carried down to considerable depths, as their limiting rise velocity is smaller than the ambient vertical water motions, and provide a significant contribution to air–sea gas flux (Source: http://amsglossary.allenpress.com/glossary/search).

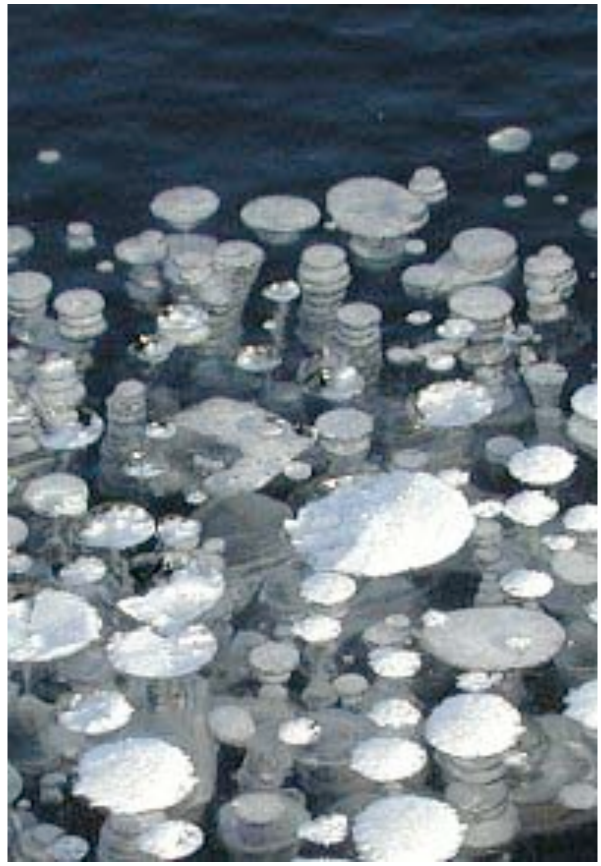
Ice bubbles in the freshwater lake below Chapman Ridge
(Source: http://www.aad.gov.au/default.asp?casid=23929)

Methane Ebullition Bubbles in Lake Ice
In northern thermokarst lakes, the decomposition of vegetation and degeneration of permafrost result in methane production or release. These methane bubble rise up through the water and become trapped at the bottom of the ice cover. Eventually, ice grows around them, trapping the bubbles in the ice (examples below).



Methane bubbles trapped in lake ice in early autumn.
(Photograph: Katey Walter)

A large pocket of methane frozen in the ice of a thermokarst lake in Interior Alaska in October 2007. (Photograph: Dragos Vas, sciencedaily.com/releases/2007/09/070911092139.htm)



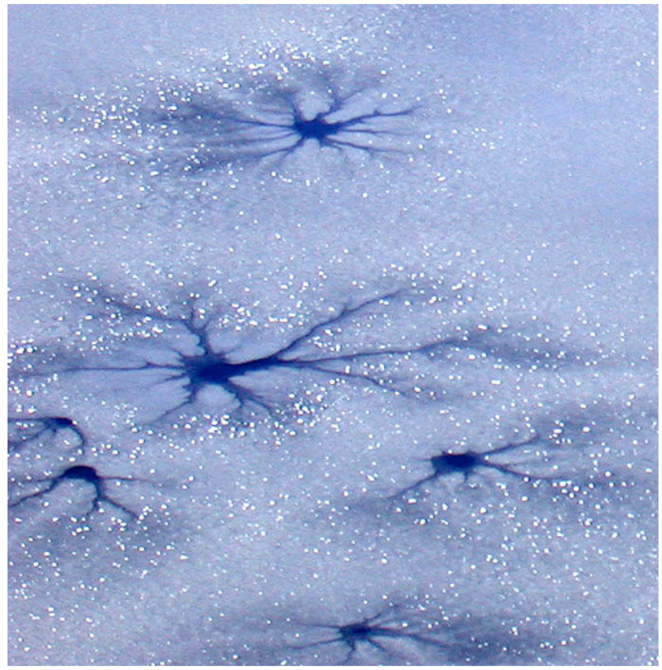
Methane bubbles trapped in lake ice in October
(Photograph: Katey Walter)

Holes in Lake Ice

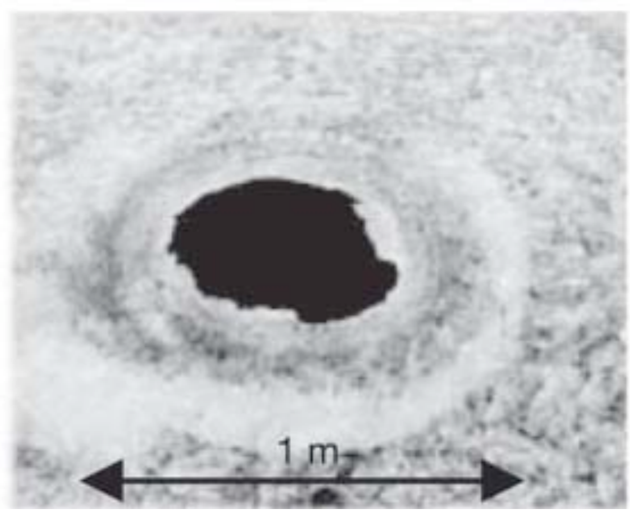
Holes can occur in ice covers at any time during the ice season. Some of these holes may be quite large and persist throughout the winter; others are small and transient.

Small holes in a very thin, new ice cover on a small pond (indicated by the arrows). These holes may simply represent the last areas to freeze over or areas where the ice has been disrupted and melted or flooded. (Image source: http://sugarmtnfarm.com/blog/2007_12_01_suarmtnfarm_archive.html)

A large open area in Lake Joutjarvi, Finland (Image source: www.panoramio.com/ photo/7123739). This open water area may be maintained by spring water flowing into the lake.



Refrozen star or spider holes on Derwent Reservoir, Derbyshire, England (4 March 2006). The cause of these features is not well understood. (Image source: http://www.flickr.com/photos/sorby/109697496/in/set-72157594181269455/)



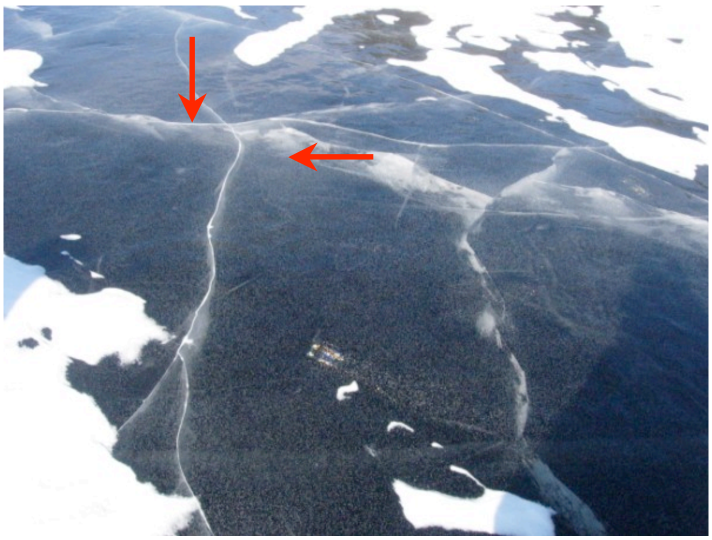
Hotspots of methane ebullition are identified as specific classes of bubble clusters or open holes in lake ice distinct from background ebullition (Photograph: Katey Walter).

Cracks in Lake Ice

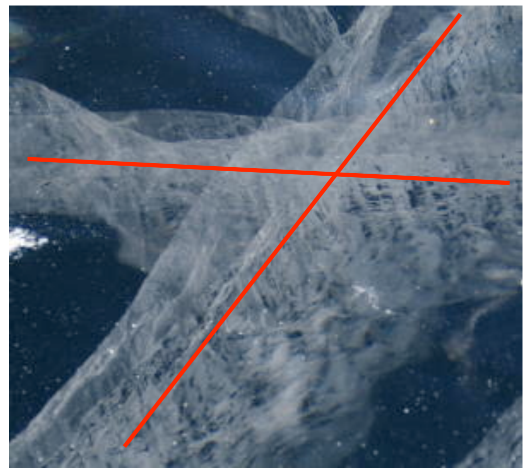
A **crack** is any fracture, break or split in the ice cover that does not result in complete separation in the ice cover (Source: http://www.geo.mtu.edu/great_lakes/icegroup/ice_terms_jake.html). They can form at anytime during the ice growth and decay season.

Thermal Cracks In Lake Ice

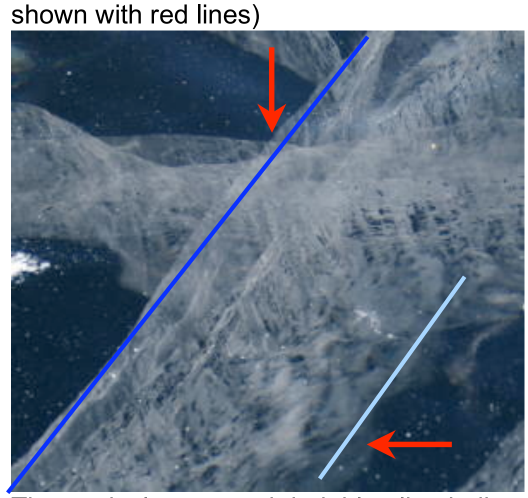
A **thermal crack** is a crack in ice cover caused by thermal contraction of the ice (Source: http://www.geo.mtu.edu/great_lakes/icegroup/ice_terms_jake.html). They form during cold nights when the ice surface cools and the bottom of the ice remains at 0°C. This causes the ice cover to become concave until it cracks. Thermal cracks open and close in response to changes in the ice temperature (Ashton, 1986). They do not necessarily extend all the way to the bottom of the ice cover, i.e., the crack does not go all the way through the ice cover.



Cracks in a black (congelation) ice cover are revealed after the snow has been redistributed by the wind. The cracks appear at the surface as strong “white” lines (vertical arrow). Because it is possible to see “into” the ice, the sides of the crack are also visible as less well defined white zones (horizontal arrow). See image at lower right. (Source: www.turtleside.com/ sutton.nh.2007-02-10.html).



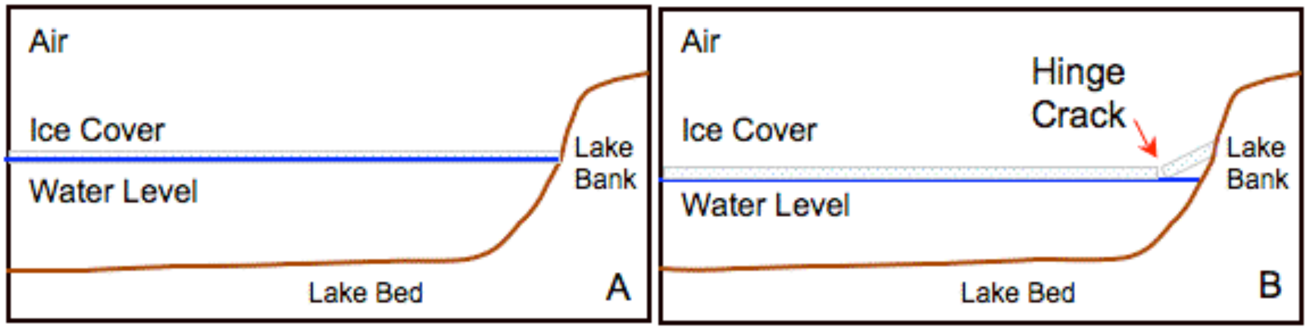
This image looks into the black ice cover in an area where two cracks intersect (general orientation shown with red lines)

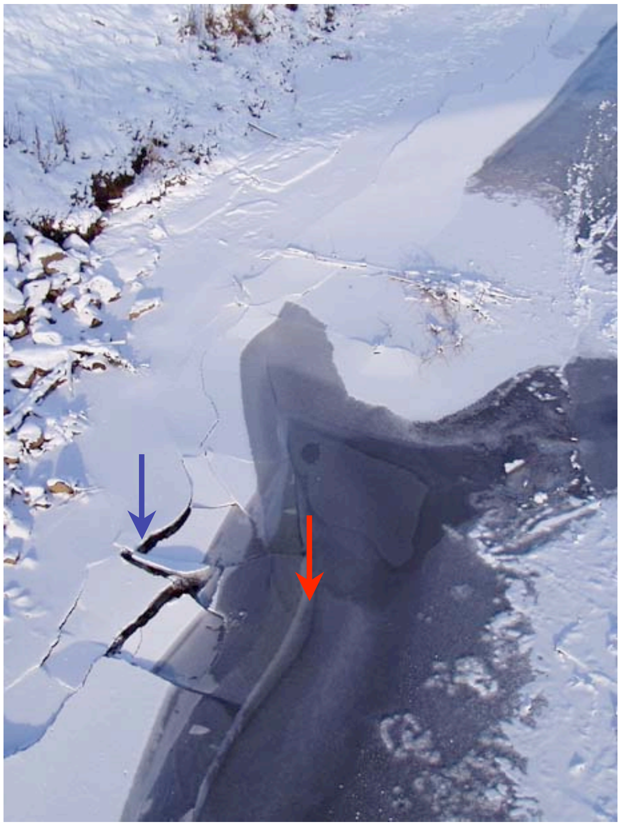


The vertical arrow and dark blue line indicate the ice surface and top of the crack. The horizontal arrow and light blue line indicate the bottom of the crack. The white zone in between the lines is the side of the crack. (Source: http://www.barrenlands.org/dispatch/April/24/index.html)

Hinge Cracks and Dropped Ice
A **hinge crack** is a crack caused by significant changes in water level (Source: http://www.expertglossary.com/weather/definition/hinge-crack). Hinge cracks can form in thin autumn ice cover.

The lake ice grows at the top of the water column and floats on top of the water (A). As the source of inflow into the lake decreases due to freeze-up of streams and precipitation falls as snow rather than rain, the level of the lake falls. . If the ice cover is not attached to the bank, i.e., free-floating, it is structurally unaffected by the decreasing lake water level. However, if the thin ice is frozen to the bank, it breaks because there is no longer any water to support it and it is to thin/weak to support the snow load. This is a hinge crack (B).




(Photograph: Martin Jeffries)

The initial, thin autumn ice cover is not very strong. This means that the ice is prone to failure when underlying water does not support it. This leads to the creation of a hinge crack. The blue arrow indicates the hinge crack in the image at left. Note how thin the ice is. The failure of the ice cover maybe sufficient to break it into pieces.

These ice pieces may become flooded (orange arrow). This could happen because the ice cover cracks but does not break and water is forced up through the cracks onto the ice forming slush on the ice surface. When breaking, the ice pieces might become wedged in the remaining ice cover in such a way that they are not “free floating” and are below the water level resulting in flooding.

Lake Ice Break-up

Lake ice break-up is the disintegration of an ice cover on land, river, or coastal waters as a result of thermal and mechanical processes. Break up of ice covering a body of water at a site; depends on ice thickness. (Source: http://amsglossary.allenpress.com/glossary/)

Snowmelt and Ponding

Break-up begins with snowmelt. This snow includes the snow on the banks of the pond and on the lake ice. **Snowmelt** is the water resulting from the melting of snow. Much of this water drains onto the lake ice cover. This melt water forms ponds on the ice cover and eventually melts through the ice or drains through cracks that develop in the ice.

Ponding on the ice occurs when this meltwater forms zones of standing water on the ice cover.

Eventually, the melt water melts through the ice or drains through cracks that develop in the ice.

A **snowmelt flood** is a substantial rise in stream or river discharge caused by snowmelt runoff (Source: http://amsglossary.allenpress.com/glossary/). Many of the smaller creeks and rivers flow into small ponds and lakes; as a consequence, this large volume of water from snowmelt can also cause a sudden rise in the water level of a pond or lake.

Snow begins to melt on the ice and adjacent land and pools on the ice. Areas of wet (saturated) snow are indicated by the arrows.

31.6 Mile Pond, AK on 19 April 2004.
(Photograph: Martin Jeffries)

As the snow melting accelerates, ponding occurs, this is, zones of standing water in the low lying areas of the ice cover appear (indicated by arrow).

31.6 Mile Pond, AK on 22 April 2005.
(Photograph: Martin Jeffries)

Rotten Ice

Rotten ice is any piece, body, or area of ice that is in the process of melting or disintegrating.
It is characterized by a honeycomb structure, weak bonding between crystals, or the presence of melt water between grains (Source: http://amsglossary.allenpress.com/glossary/).

One way that a lake or pond can break up is by in situ (in place) melting (thermal process).

After the snow melts, the white ice cover is exposed. Here is an example of spring ice cover on which hard, icy snow and snow ice are visible.

(Photograph: Martin Jeffries)

As the ice melts further, the black ice portion of the ice cover is exposed. Thermal cracks are clearly visible. The yellow field book is included for scale (12 x 19 cm).

(Photograph: Martin Jeffries)

As melting continues, water may pond on the surface of the ice and small areas of open water, in very shallow sections of the pond, may form.

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(Photograph: Martin Jeffries)

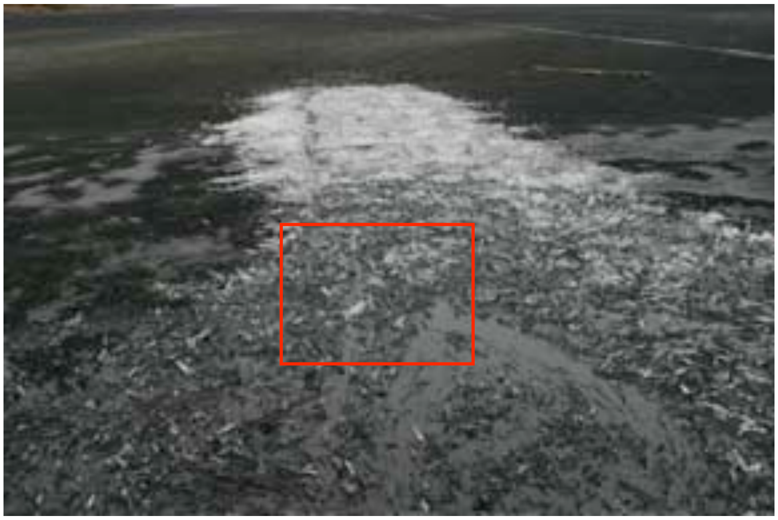
Advanced melting of the ice cover leads to a reduction in ice area, the formation of candle ice (see below), and disintegration of the ice cover.

(Photograph: Martin Jeffries)

Candle ice

Candle ice is a form of rotten ice. It is disintegrating river or lake ice consisting of ice prisms or cylinders oriented perpendicular to the original ice surface; these “ice fingers” may be equal in length to the thickness of the original ice before its disintegration (Source: http://amsglossary.allenpress.com/glossary/). Candle ice is formed when black ice melts in place; melting occurs along crystal boundaries perpendicular to the ice surface.

The long crystals of candle ice have the appearance of bundles of needles or “candles” hence its name. (Photograph: Martin Jeffries)



Candle ice is an intrinsically weak material that is easily broken. This is a candle ice cover that has been broken up by a shovel. (Photograph: Martin Jeffries)

This is a close-up of area in the box in the above image. It shows the elongated candle ice crystals. (Photograph: Martin Jeffries)

Moat

A **moat** is standing melt water on the ice cover, or open water, that encircles the pond or lake. This zone becomes a focus of subsequent ice disintegration.

Snowmelt, from the snow on the ice and the bank, forms a moat around the periphery of the pond on top of the ice. Energy can be transferred from the water to the underlying ice promoting melting.

(Photograph: Martin Jeffries)

Lake ice melts out around the edges of the pond/lake creating an open water moat. The heat radiated from the vegetation on the bank assists in this process.

(Photograph: Martin Jeffries)

This zone steadily expands as the ice melts from the top and the side. It can become an important stop over point for migrating waterfowl.

(Photograph: Martin Jeffries)

Once an open water area is established, it is possible for the ice to move on the pond in response to local winds, which often accelerates the disintegration of the ice cover.

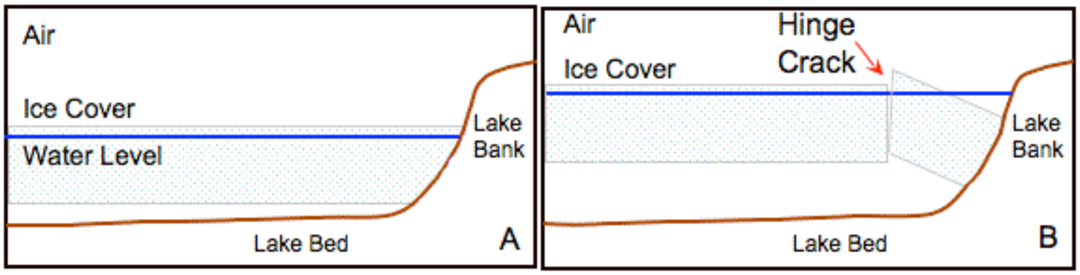
(Photograph: Martin Jeffries)

Hinge Cracks and Ice Cover Tipping

A **snowmelt flood** is a substantial rise in stream or river discharge caused by snowmelt runoff (Source: http://amsglossary.allenpress.com/glossary/). Many of the smaller creeks and rivers flow into small ponds and lakes; as a consequence, this large volume of water from snowmelt can also cause a sudden rise in the water level of a pond or lake.

A **hinge crack** is a crack caused by significant changes in water level (Source: http://www.expertglossary.com/weather/definition/hinge-crack). When a hinge crack forms in the spring ice cover, the ice is free to move in response to environmental forces.

Spring snowmelt can cause the water level in the pond to rise dramatically. The lake ice floats on top of the water (A). If the ice cover is not anchored to the lakebed or bank, it will freely rise with the increasing lake water level. However, if the ice is frozen to the lakebed (in shallow areas), the floating portion of the ice cover will flex and break forming a hinge crack (B).



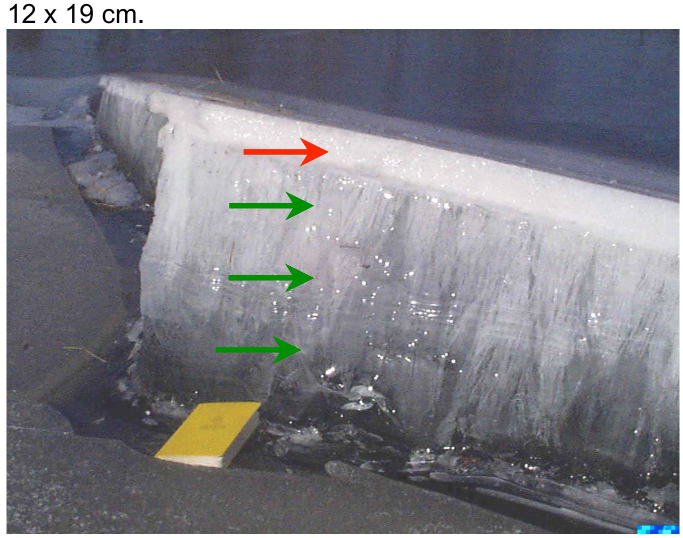
The hinge crack is indicated in the image below by the blue arrow. The ice at the left of this arrow is "free floating" at the new water level.

The orange arrow indicates a zone where the ice cover is frozen to the lakebed or bank. The ice is held in place below the new water level and water floods over the ice. The ice between the zone frozen to the lakebed and the hinge crack is "tipped" up.

(Photograph: Martin Jeffries)

The edge of the tipped ice face along the hinge crack, clearly shows the white (snow) ice and black (congelation) ice boundary.

The red arrow indicates the white (snow) ice. The green arrows indicate the black (congelation) ice. The black ice appears light grey (top) to dark grey (bottom). Note the vertical structure in the congelation ice. The field book is 12 x 19 cm.



(Photograph: Martin Jeffries)

These ice hinges can become one of the edges for ice blocks as the ice cover breaks up. These ice blocks can become stranded as the break-up proceeds (see below).

Ice Blocks

The ice cover can break up into large **ice blocks**. This will happen when thermal cracks and other ice cover flaws preferentially melt out because liquid water (snowmelt) drains into and eventually through them. Once the ice cover is weakened in this manner, and some open water is present, the wind can begin to move the ice cover around the pond causing further mechanical break-up.

On 2 May 2005, the ice cover has broken up into large blocks of ice. The ice blocks cannot move very much because there is little open water in the pond.

(Photograph: Martin Jeffries)

By 6 May 2005, the large ice blocks have broken up into smaller blocks. These blocks can be moved around the pond by persistent winds because the amount of open water has increased.

(Photograph: Martin Jeffries)

Stranded Ice Blocks

Large ice blocks can be stranded in shallow water or on another pieces of ice when the wind moves the ice from one end of the pond to the other and one piece of ice is forced underneath another.

(Photograph: Martin Jeffries)

Ice blocks can be stranded on the bank of the pond. This may happen when the lake water level falls rapidly. A rapid fall in water level may occur if an ice jam breaks and water is allowed to flow freely out of the pond.

(Photograph: Martin Jeffries)

Resources

These Alaska Lake Ice and Snow Observatory Network (ALISON) web pages provide some basic water and ice background:

- Background – Lake Ice Science: http://www.gi.alaska.edu/alison/ALISON_objective3.html
- Lake Ice And Snow Science: Why Study Lake Ice and Snow? Changes in Freshwater Ice http://www.gi.alaska.edu/alison/ALISON_SCIENCE_ChangeLakes.html
- Lake Ice and Snow Science – Basic Concepts: H_2O Phase Diagram http://www.gi.alaska.edu/alison/ALISON_SCIENCE_BConcepts.html
- Lake Ice and Snow Science – Basic Concepts: Hydrological Cycle
- http://www.gi.alaska.edu/alison/ALISON_SCIENCE_BC_H2OCycle1.html
- Lake Ice and Snow Science – Basic Concepts: Thermal Conductivity
- http://www.gi.alaska.edu/alison/ALISON_SCIENCE_BC_ThermCon.html
- Lake Ice and Snow Science – Basic Concepts: Albedo
- http://www.gi.alaska.edu/alison/ALISON_SCIENCE_BC_Albedo.html

The American Meteorological Society Glossary of Meteorology http://amsglossary.allenpress.com/glossary

Climate Change Project Jukebox - http://uaf-db.uaf.edu/jukebox/ClimateChange/htm/sam.htm#top
Samuel Demientieff's talk at the Annual OLGC Teachers Meeting December 2003 in Fairbanks has some pictures, definitions and observations about Global Change.

CRREL River Ice Guide and Glossary http://www.crrel.usace.army.mil/ierd/ice_guide/iceguide.htm

Expert Glossary http://www.expertglossary.com/science

MichiganTech – Geological & Mining Engineering & Sciences: Definitions of Lake Ice Terms
http://www.geo.mtu.edu/great_lakes/icegroup/ice_terms_jake.html

Nature Watch - Ice Watch: volunteer lake and river monitoring program in Canada.
http://www.naturewatch.ca/english/icewatch/

River Lake Ice Engineering, George D. Ashton (1986}